PROTECTIVE ENSEMBLES FOR FIREFIGHTING CHALLENGE THE BALANCE AND STABILITY OF FIREFIGHTERS

STRATEGIC MANAGEMENT OF CHANGE

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ABSTRACT

King's Point Volunteer Fire District is a rural, residential community that has recently experienced tremendous growth, as well as an increase in both emergent and non-emergent incidents. With the increase of incidents, King's Point has experienced a number of firefighters, with no apparent sensory deficits, experience slips and falls while wearing protective clothing ensembles. The purpose of this research project was to investigate the affects on a firefighter's center of gravity (COG) and balancing ability when wearing a station uniform as compared to wearing protective clothing ensembles, coupled with a self contain breathing apparatus.

This project employed evaluative and historical research methods to (a) determine what deficiencies are encountered while wearing protective ensembles in order to position one's center of gravity (COG) over the base of support (BOS) in a given sensory environment, (b) determine the physiological impairments associated with the firefighter's age as it affects one's center of gravity (COG) over the base of support (BOS) in a given sensory environment, (c) determine the advantages of computer-based assessment to learn firefighters' strategies in maintaining balance, (d) determine some of the limitations and deficiencies of computer-based assessment to learn firefighters' strategies in maintaining balance, (e) determine if computer-based assessment replicates the reality of firefighters' strategies in maintaining balance, and (f) determine if computer-based assessment has an influence on firefighters learning their strategies to maintain balance.

The procedure used involved a review of academic and trade journal publications, interviews, questionnaires, and a clinical study. A comparison of literature reviews of balance, physiological impairment associated with balance, as well as human mediated testing methodologies for protective clothing ensembles to computer-based testing was made. In addition, interviews and a questionnaire were used to obtain chief officers' perceptions of the need to evaluate firefighters' balance and stability while wearing protective clothing ensembles, as well as if slips and falls are prevalent to firefighters wearing protective clothing ensembles.

The major findings of this research were slip and falls account for 25 percent, respectively, of fireground injuries to firefighters, and that protective clothing ensembles impair balance. The recommendation resulting from this research indicated a need for King's Point Volunteer Fire Department to use computer-based assessment for selection and procurement of protective clothing ensembles. However, it was also noted that King's Point, as well as many of the municipalities in Central Florida, do not have the physical budget to purchase computer-based assessment to determine which type of protective clothing ensembles negatively affect balance prior to procurement of the ensembles. Therefore, it was recommended that another agency, such as the National Fire Academy (NFA) or the National Fire Protection Association (NFPA), do further research using computer-based assessment to evaluate protective clothing ensembles and their affect on the balance of firefighters.

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INTRODUCTION

"It wasn't too long ago that the traditional protective clothing worn by firefighters consisted of long coats constructed of rubberized or coated heavy materials in combination with hip-high boots" (Stull, 1999, October, p. 23). In addition, protective clothing ensembles were "often selected on the basis of appearance, color, fit, or cost rather than on the basis of physiology" (United States Fire Administration [USFA], 1993, September, p. 1). The performance criteria for protective clothing ensembles were to keep firefighters dry and protect them from direct flame contact and smoke. Because of this, more often than not, they were hot, heavy and bulky (Stull, 1999, October) and contributed to heat stress, fatigue and injury. However, in recent years, there have been great technical advancements in protective clothing ensembles for firefighting which have contributed to a massive improvement in protection against a variety of different hostile environments. These technical advancements can be attributed to studies commissioned by the International Association of Fire Fighters (IAFF) and the United States Federal Emergency Management Agency (USFEMA). In addition, the standards established by the National Fire Protection Association (NFPA) dictated functional performance requirements for protective clothing ensembles (Stull, 1999, October). The main goal of these studies was to design, fabricate, laboratory test and field-test an integrated protective clothing ensemble for firefighters. Also, the protective clothing ensembles had to provide "heat and flame protection against all types of fire hazards, waterproofness against rain and extinguishing agents used in fire attack, breathability to prevent increases in temperature and humidity inside the suite and comfort for ease of movement" ("Firefighting fabrics," 1997, October, p. 11). Because of these technical advancements in protective ensembles, protocols for measuring clothing performance criteria were developed. Protective ensembles were field-tested using anthropeometric and physiological tests. However, the focus of the field test was to check for comfort, freedom of motion, agility and heat stress (Duffy, Sawicki & Beer, 1985). Nonetheless, the number of firefighters' injuries regarding flame contact have been gradually decreasing downward. On the other hand, other injuries, such as the number of slip and falls have remained the same or increased with these technical advancements in protective clothing ensembles.

The problem that served as a catalyst for this research was that King's Point Volunteer Fire Department has begun to experience a number of firefighters with no apparent sensory deficits, experiencing slips and falls at emergent and non-emergent incidents. Because there are no apparent sensory deficits in the firefighters, and no existing physiological tests to indicate that balance is not impaired while wearing protective clothing ensembles, this condition has been hypothesized to be a result of impaired balance due to wearing the protective ensembles that block available afferent information from visual, vestibular and proprioceptive inputs. However, some may be of the opinion that it is related to physiological impairments associated with the shift in age from younger volunteer firefighter population to that of an older volunteer firefighter population.

The purpose of this research, by means of literature review, questionnaires, interviews, and clinical studies, was to evaluate both internal conditions and their relationships and the external forces and their impact on protective clothing ensembles regarding slip and falls. Evaluative and historical research methods were employed to answer the following questions:

1. What deficiencies are encountered while wearing full protective ensembles in order to position one's center of gravity (COG) over the base of support (BOS) in a given sensory environment?

2. Do physiological impairments associated with the firefighter's age affect one's center of gravity (COG) over the base of support (BOS) in a given sensory environment?

3. What are the advantages of using computer-based assessment to learn firefighters' strategies in maintaining balance?

4. What are some of the limitations and deficiencies of computer-based assessment to learn firefighters' strategies in maintaining balance?

5. Does computer-based assessment replicate the reality of firefighters' strategies in maintaining balance?

6. Will computer-based assessment influence firefighters' ability to learn strategies to maintain balance?

BACKGROUND AND SIGNIFICANCE

King's Point Volunteer Fire Department is a totally volunteer fire department that is under contract with Osceola County, Florida to provide first response basic life support and sole service fire protection to an area encompassing 14 square miles. King's Point's fire district consists of low to medium density residential areas, rural and residential interface regions, medium density commercial, medium level industrial, and medium to high-speed intrastate highway systems. This once rural area has experienced tremendous growth in recent years because of the continuous encroachment of commercial and industrial businesses that support the vibrant economic environment surrounding Walt Disney World.

This tremendous development has caused a change in the demographics within King's Point Volunteer Fire Department. Job opportunities for volunteer firefighters, who were only able to work part-time prior to the resonant economic environment, are now being employed full-time by these commercial and industrial businesses. This has also caused King's Point to struggle with recruitment and retention of volunteers within the community because of the limited number of potential applicants. Additionally, this has caused a shift in the age of those potential applicants from a younger population to an older population.

The economical growth within the community has increased the population density in the medium density residential areas. Therefore, both the numbers of emergent and non-emergent incidents to which King's Point responds have increased. Because of this, the number of slips and falls to firefighters with no apparent sensory deficits has become more and more prevalent.

The problem addressed in this paper relates to the National Fire Academy's (NFA) *Strategic Management of Change* course, Module 2, which emphasized that the Change

Management Model is a tool to be used by executive fire officers to manage change. During the presentation and discussion of Module 2, the focus was on continuously searching for ways that executive fire officers can improve performance on a day-to-day basis by recognizing internal conditions and their relationship to change management, as well as recognizing external forces and their impact on change management. A portion of this focus was to use the four phases of the Change Management Model: Phase 1--Analysis, Phase 2--Planning, Phase 3--Implementation, Phase 4--Evaluation--Institutionalism. This paper will explore the Analysis Phase of the Change Management Model to determine if slips and falls are a result of protective clothing ensembles blocking available afferent information from visual, vestibular and proprioceptive inputs, as well as whether or not the sense of balance declines with age due to combined vestibular, proprioceptive and visual losses resulting in the potential higher risk of falls.

LITERATURE REVIEW

The literature review was performed to analyze the existing situation of slips and falls of firefighters, in both younger and older populations, as well as if slip and falls are prevalent to firefighters while wearing protective clothing ensembles. Also to review testing protocols to measure performance criteria for protective clothing ensembles, and to review physiological impairments associated with impairment balance and aging. The literature review involved a search of trade journals, textbooks, the Internet, and interviews. The following literature review provides additional support to parallel and correlate the research proposed. This section discusses:

1. Slips and Falls
2. Protective Ensembles
3. Balance Training for Improved Performance
4. Balance
5. Maintaining Stability
6. Falls Related to Load Handling
7. General Physiological Impairments Associated with Impaired Balance
8. Physiological Impairment Associated with Aging
9. Computer-Based Assessment of Balance

Slips and Falls

Dunn (1994, June) stated that "falls, slips and missed jumps are the number one cause of fireground injury" (p. 20). Studies conducted by the Volunteer Fireman's Insurance Service (1996) paralleled Dunn (1994, June) by suggesting that the order of the greatest number of injuries to firefighters to the least number of injuries were:

1. Fell, slipped, or jumped, 27.0 percent;
2. Stepped on or contact with an object, 24.3 percent;
3. Exposure to fire products, 13.5 percent;

4. Extreme weather, 10.8 percent;
5. Struck by objects, 5.4 percent;
6. Exposure to chemicals or radiation, 2.7 percent;
7. Caught or trapped, 0.0 percent;
8. Other injuries, 0.0 percent (p. 2).

Dunn (1994, June) also wrote in 1992, that the statistics revealed that 53 percent of firefighters "were hurt while fighting fire, and most of their injuries were caused by falls, slips and jumps" (p. 20). An analysis of injuries in the Orange County Emergency Services (OCES) District No.1 by Scott D. Kerwood (1997, March) supports Dunn's (1994) finding that the leading fireground injury identified in his study was falls, slipped or jumped. However, the tenth edition of *Fire in the United States* (1995) reported that the largest category of firefighters' injuries were inflicted by contact with or exposure to flames or smoke. Contact and exposure accounted for 36 percent of injuries. The second highest category, according to the tenth edition of *Fire in the United States* (1995), was "overexertion and strain [23 percent], followed closely by fell or slipped [19 percent]" (p. 171). Additionally, Angle (1999) suggested that historically fireground injuries represent the highest number of injuries and of those, overexertion and strain (25.6 percent), and fell, slipped and jumped (25.3 percent) were the highest. Although there are discrepancies regarding the number one cause of fireground injury between Dunn (1994, June), Kerwood (1997, March), and the Volunteer Fireman's Insurance Service (1996), when compared to the tenth edition of *Fire in the United States* (1995) and Angle (1999), slips and falls are still a significant problem in fireground operations.

Dunn (1994, June) said after observing firefighters fall at some incidents, he conducted research into fall injuries and stated:

> There are some misconceptions about how and where firefighters fall during fires. Most falls are not from heights. We become naturally cautious about fall injuries when we climb ladders or fire escapes and work on roof tops, but actually most falls occurring during fire operations, happen at the ground level (over 60 percent). We slip on icy streets or pavements when stretching hoses or raising ladders; or we trip over a hose or some unseen obstruction at night fires (p. 20).

The United States Bureau of Labor Statistics (1999, February) reported 40 percent of all falls are from an elevation, and the other 60 percent are slip and falls on the same level (ground level). This statement coincides with Dunn's (1994, June) research regarding slips and falls. Additionally, Dunn (1994, June) suggested that firefighters could fall or slip because they are under physical and emotional stress during fireground operations and that makes them vulnerable to falls. He also suggested that stress would cause "tunnel vision" or the "candle moth" syndrome causing firefighters to become focused on the fire and block out the surrounding environmental hazards that could cause them to fall, slip or misjudge a jump. In addition, common extrinsic hazards, such as clutter, hoselines in pathways, inadequate lighting, uneven surfaces, and slippery surfaces are also given as a reason that firefighters slip and fall. Pagels (1987, May) suggested that a better understanding of injuries to firefighters would help chief officers identify corrective measures or actions needed to minimize the total number of injures.

Protective Ensembles

Duffy, Sawicki, & Beer (1985) wrote, "In 1971, the International Association of Fire Fighters [IAFF] requested the National Aeronautics and Space Administration [NASA], to initiate a technology transfer program to develop state-of-the-art protective clothing for structural fire fighters" (p. 1). Duffy et al. (1985) also stated that:

> The objective of this joint adventure was to design, fabricate, laboratory test and field test an integrated protective clothing ensemble for fire fighters that would address the known limitations of then available equipment, including severe heat stress, interference with movement and inadequate protection, especially from the heat experienced during flashovers and backdrafts (p. 1).

Duffy et al. (1985) also wrote that in order to accurately evaluate protective ensembles, sophisticated examinations of performance as well as physiological and anthropometric testing were conducted. These tests included:

1. Thermal protective performance
2. Breaking strength
3. Flame resistance
4. Thermal shrinkage resistance
5. Heat resistance
6. Heat resistance with dripping and ignition only
7. Cleaning shrinkage resistance
8. Tear resistance
9. Char resistance
10. Water absorption resistance
11. Water penetration resistance high pressure
12. Water penetration resistance low pressure
13. Thread heat resistance
14. Luminous intensity
15. Corrosion resistance
16. Heat resistance with assessment of ignition and retention of functionality only

Duffy et al. (1985) wrote that five firefighters were used to test the protective ensembles in 14 cities from January through August, 1985. The conditions ranged from "-30°F with -100°F wind chill and snow, through 100°F with 100 percent humidity and downpours, to 120°F with 10 percent humidity" (p. 9). Their focus in this physiologic and anthropometric test was to evaluate the impact of the ensembles in terms of freedom of motion and heat stress by having firefighters perform firefighting tasks while wearing the protective ensembles. Also, *The Minimum standards on structural firefighting protective clothing and equipment: A guide for fire service education and procurement* (USFA, 1993, September) suggested that to ensure performance standards on protective clothing ensembles, a series of field tests were conducted to measure adequate protection and to evaluate wearer limitations. After the field tests identified the limitations, the IAFF then worked with the manufacturers to address each limitation, as well as to redesign materials to produce new fabrics. "Firefighting fabrics" (1997, October) reported on the new fabrics in protective ensembles stating that the "improvement in fabric technologies has seen a vast improvement in the range of protective materials, offering different characteristics, available to the firefighter" (p. 15). "Firefighting fabrics" (1997, October) also stated that the main concerns with firefighters' protective clothing were "heat and flame protection against all types of fire hazards, waterproofness against rain and extinguishing agents used in fire attack, breathability to prevent increases in temperature and humidity inside the suit, and comfort for ease of movement" (p. 11). Stull (1999, July) described some of the new technology available in the protective clothing ensembles and paralleled Duffy et al. (1985) and "Firefighting fabrics" (1997, October) in that the main concerns were comfort and ease of movement, in addition to the protective ensemble providing consistent levels of protection against hostile environments. Stull (1999, July) wrote, "as with any item of firefighters' protective clothing, close attention must be paid to the design and performance of selected items" (p. 61).

Balance Training for Improved Performance

Runge, Shupert, Horak, & Zajac (1996) wrote, "although people spend countless, seemingly effortless, hours standing during their lifetime, the task of maintaining balance is actually complex" (p. 1). Runge et al. (1996) also suggested that balance could be improved by using qualitative and quantitative techniques. James' (1998, November 31) findings agreed with Runge et al. (1996) by taking it a step further and suggesting that many professionals use knowledge and concepts from biomechanics to train, rehabilitate and prevent injuries. He also suggested that teachers, coaches and fitness professionals use qualitative and quantitative techniques to analyze the internal and external factors that influence balance and to enhance skill development of athletics. Laskowski, Newcomer-Aney, & Smith (1997, October) espoused the idea of proprioception performance in athletics and suggested that proprioception-based rehabilitation and training could improve afferent input of the joint position sense and their efferent output to maintain control of balance. Laskowski et al. (1997, October) also indicated that athletes who had a "postural sway greater than 2 standard deviations above normal had a statistically significant higher risk of injury" (p. 2). Laskowski et al. (1997, October) conducted research that used proprioceptive training with five different phases of balance training on various platforms that challenged the balance system. Laskowski et al. (1997, October) wrote that proprioceptive training "significantly reduced the incidences of anterior cruciate ligament [ACL] injury" (p. 2).

Quinn (1999, July) indicated that balance is the basic skill needed in practically everything that we do from simple standing, walking and running, to more strenuous physical activities. Quinn (1999, July) also suggested that many times injuries occur even though the individual is trained in the activity in which they are participating. Quinn (1999, July) suggested that a variety of injuries often have nothing to do with the strength or the endurance of the individual, or even the flexibility of the individual. Quinn (1999, July) states that "more often than not, sprains and strains have to do with balance" (p. 1). She also suggested that balance could be learned by improving our proprioception within the muscles. Anna Evans (2000, January 4, personnel communications) espoused Quinn's (1999, July) research stating that proprioception training is highly common in rehabilitation after injuries. Anna Evans (2000, January 4, personnel communications) stated that "balance, even under load while wearing protective ensembles, could be learned by improving proprioception with the muscles." In addition, Quinn's (1999, July) studies are congruent with those of Evan's (2000, January 4, personnel communications) and Laskowski et al. (1997, October) studies in that proprioception can be used to "prehabilitate" or avoid injury. Mark Wheller's (1997, November) writings postulated Quinn's (1999, July) findings by stating that proprioceptive response of the receptors in muscles, tendons, joints, and skin detect the position and movement of the body, then signal the brain to make necessary muscular adjustments as needed. Wheller (1997, November) also suggested that balance could be learned by improving our proprioception within the muscles to immediately adjust your posture and center of gravity (COG) to regain balance and prevent injuries.

Balance

James (1998, November 31) suggested that balance is the ability to position one's center of gravity (COG) over the base of support (BOS) in a given sensory environment. Balance is achieved through a complex process involving sensory detection of body motions, integration of sensorimotor information within the central nervous system, and delivery of appropriate musculosketetal responses. Horak (1991) agreed that balance results from an interaction of many complex systems, and subsystems. Givens' (1999, October) studies, are congruent with those of James (1998, November 31) and Horak (1991) studies stating that balance and postural control is how "we stabilize ourselves to maintain a position or to perform movement safety in a controlled manner. Balance is affected by musculosketetal constraints, sensory organization and motor coordination strategies" (p. 1).

James (1998, November 31) suggested that although balance results from many complex systems, the location of the center of gravity (COG) could change depending on the position of the person's body that also affects stability and balance, as well as strategies. Miller's (1999) research agreed with James (1998, November 31) and he added "COG changes during various activities according to the build of the person" (p. 1). Nashner & McCollum (1985) agreed that the COG changes during various activities and added that when the COG is located within the limits of stability (LOS) boundary, either an ankle strategy, hip strategy, or combination of the two can be used, depending on the task being performed. Nashner & McCollum (1985) also found ankle strategies are the most effective when the COG moves slowly and between positions located well within the LOS boundary. They also noted that hip strategies are most effective for rapid movements, such as stepping, stumbling, or both.

James (1998, November 31) also found that external weight repositions the COG of the person and he used an example of picking up a heavy object and noticing which direction your body leans in order to compensate for the extra weight. James (1998, November 31) stated that "body lean is a method for repositioning your COG over your feet [base of support] so that you will not lose your balance" (p. 1). James (1998, November 31) also stated, "understanding the behavior and factors that affect the COG is important because a body (object or person) behaves mechanically as if all its mass were concentrated at the COG" (p. 1).

Horak & Nasher (1986) found that balance consisted of a limited repertoire of central motor programs that they called ankle strategies and hip strategies. In addition, Horak & Nasher (1986) found in their research that balance is maintained by postural orientation from sensory systems including visual, somatosensory and vestibular. Zimmer's (1996, February 1) research with circus high wire performers postulated Horak & Nasher (1996) research adding that if the stretch-sensitive nerves in the ankle are blocked or desensitized to the point where the performers do not know that they are swaying slightly, then they are in trouble. This is because the balance somatic receptors are not able to perceive sensation. Also, Zimmer's (1996, February 1) experiment results suggest that circus high wire performers absolutely require sight to let them know their postural orientation. Oddsson's (1990) research paralleled Horak & Nashers' (1986) and Zimmer's (1996, February 1) research finding that the sensory detection of body motion and balance is accomplished through three systems; the visual, vestibular and proprioceptive systems. Oddsson (1990) also noted that if afferent input from the vestibular or proprioceptive systems were blocked, then the visual system would have to maintain balance.

Maintaining Stability

Oddsson, Persson, Cresswell & Thorstensson (1999) stated, "the main goal of the postural control system is to maintain stability in all situations and during all tasks that are performed" (p. 1). They also suggested that external perturbation of posture triggers specific automatic responses that send warning signals to the central nervous system, which initiate the appropriate compensations to maintain balance. In addition, Oddsson et al. (1999) suggested that these automatic responses control balance through postural responses and voluntary movements that restore equilibrium by evenly distributing the body's weight while the eyes maintain focus on a fixed object. Oddsson et al. (1999) also said that few studies have investigated the interaction between automatic postural responses and voluntary movements. Oddsson et al. (1999) stated that, it has been hypothesized that certain combinations of voluntary movement and postural perturbation could cause conflict between postural and voluntary motor command simultaneously requiring different functions of the same muscle, muscle group, or both. Thus, conflict in muscle function imposes an increased risk of injury, risk of falls, or both. A platform was designed to study triggered postural responses when the perturbation was delivered during an ongoing voluntary movement. Oddsson et al. (1999) stated that this platform, termed BLADER (BALance DisturbER), was designed to cover a greater range of perturbations than most previously used platforms.

Falls Related to Load Handling

Oddsson (1999, November) wrote, "conflicts between motor commands is probably common during different occupational activities, such as walking, lifting or carrying loads, as well as during reaching for or pushing and pulling objects" (p. 1). Oddsson (1999, November) conducted experiments using a specially designed moving platform (BALance DisturbER) and had each subject lift a 20 kg load while perturbed randomly at the feet in an anterior-posterior direction during the vertical lifting. Oddsson (1999, November) also used a video based motion analysis system in conjunction with recording the muscle activity from the soleus, tibialis anterior, anterior deltoideus and erector spinae. Oddsson (1999, November) found the presence of a motor command conflict in the muscles and hypothesized:

> That certain combinations of voluntary movement and postural perturbation, such as slip or trip, may cause a conflict between postural and voluntary motor commands simultaneously requiring different functions of the same muscle and or muscle group. It is further suggested that this conflict increases the risk of direct tissue injury and or a fall (p. 1).

General Physiological Impairments Associated with Impaired Balance

The Mayo Clinic (1999, February 22) on their web page www.mayo.edu. stated, "forty percent of people over the age of 40 experience dizziness or balance problems at some point in their life" (p. 1). The Mayo Clinic web site contributed this imbalance or risk of falling to loss within the peripheral vestibular system. Vestibular Disorders Association (1999, November) on their web page www.teleport.com suggest that patients with vestibular disorders often report fatigue and loss of stamina and an inability to concentrate. They also added that 90 million Americans (respectfully 42 percent of the population) experience some form of vestibular disorders in all age groups and walks of life.

Leibowitz & Shupert (1985) suggested that another area of physiological impairment associated with impaired balance are the visual sensory systems. Horak & Woollacott (1996) postulated Leibowitz & Shupert (1985) writings and added that visual sensory transmits less light to the retina and this results in the loss of visual contrast sensitivity that causes problems with contour and depth perception. Leibowitz & Shupert (1985) added that the visual sensory system is mainly comprised of the spatial orientation. In addition, they stated that the spatial orientation includes the vestibular and somatosensory systems. Leibowitz & Shupert (1985) postulated that the systems which maintain postural sway are the vestibular and proprioceptive, as well as the eyes moving with the body (visual). In addition, Leibowitz & Shupert (1985) espoused that normal corrective movements to maintain postural sway increased with age, reflexes diminish and reaction time increases related to vision, vestibular function and proprioception. Also, cognitive impairment increased the risk of slips and falls in hazardous environments.

Horak & Woollacott (1996) also suggested that there are multiple contributing factors associated with impaired balance such as intrinsic and extrinsic environmental factors, in addition to the general physiological impairments associated with impaired balance. Horak & Woollacott (1996) also postulated that many of these multiple factors can be remedied and that both intrinsic and extrinsic factors associated with falls could be corrected. Horak & Woollacott (1996) listed extrinsic environmental factors as:

1. Wet, slippery surfaces
2. Uneven, cluttered surfaces
3. Stairs, curbs
4. Lighting--improper or inadequate

5. Sudden changes in surfaces or lighting
6. Trips, obstacles
7. Jostle in crowds (p. 1).

Horak & Woollacott (1996) also listed intrinsic factors as:

1. Neural [sensory, perceptual, motor, higher level adaptive, cognitive]
2. Musculoskeletal [strength, range of motion]
3. Cardiovascular [postural hypotension]
4. Pharmacological [diuretics, antihypertensives, antidepressants, antipsychotics, antiparkinsonism] (p. 2).

Horak & Woollacott (1996) suggested that balance requires the complex interactions of many subcomponents of the neural and musculoskeletal systems. They listed them as:

1. Neural subsystems
2. Sensory
3. Motor
4. Adaptational
5. Cognitive [fear of falling, attentional]
6. Muscle [strength, tone]
7. Skeletal [tendons, ligament] (p. 3).

Physiological Impairment Associated with Aging

Sabelman, Gadd, Chesney, et al. (1994) and Whipple, Wolfson, Derby, Singh, & Tobin (1993) performed experiments in altered sensory function and balance in older persons. Both used younger and older populations who had no apparent sensory deficits or history of falling as the study group. Sabelman, Gadd, Chesney, et al.(1994) used various motion tasks to analyze their responses to the control of balance perturbations. Some of the motion tasks were walking, quiet standing with eyes both open and closed, walking up and down three steps, and rising from and sitting in a chair. Sabelman, Gadd, Chesney, et al. (1994) used video cameras and a small wearable instrument that gathers balance information from the accelerations of a person's head and torso called an accelerometic motion analysis. The accelerometic motion analysis monitored the differences between head and body vertical acceleration peaks during each of these motion tasks. Whipple, et al. (1993) used a computer-based force platform called the Balance Master to measure postural sway. The Balance Master provides quantitative measures of center of gravity (COG) and limits of stability (LOS) sway referenced to an age-matched normative database. Sabelman, Gadd, Chesney, et al. (1994) noted that vertical acceleration peaks were higher for the older group when ascending and descending stairs. Through each motion task, the accelerometric system produced similar results. Sabelman, Gadd, Chesney, et al. (1994) theorized that this was possibly due to stiffening of intervertebral discs in the elderly. In addition, Sabelman, Gadd, Chesney, et al. (1994) suggested that hearing and vision declines with age and impaired the balance in the study population. White & Maisey (1997) suggest postural stability is a physiological impairment affected by the aging process. Sabelman & Winograd

(1999, July) paralleled White & Maisey (1997) adding that, "the sense of balance declines with age to combined vestibular, proprioceptive and visual losses, resulting in impaired mobility and increased risk of injurious falls" (p. 1). White & Maisey (1997) stated:

> Studies have found elderly subjects were slower to implement postural corrections and their corrections were less coordinated than those of younger adults. The result may indicate that the elderly may be less able to correct small changes in posture and therefore lead to an increase risk for falls (p. 3).

Whipple's et al. (1993) studies showed significant declines with age regarding sensory function and balance. Their study also reported that the LOS were evident beginning at age 60, then declined at the rate of 16 percent per decade thereafter. Whipple et al. (1993) found LOS distances decreased and eyes closed sway increased with age. Also, while using the Balance Master, their research demonstrated significantly greater postural sway in the elderly, as well as their being less likely to be able to balance during changing environments. Sabelman, Gadd, Chesney, et al. (1994) and Whipple et al. (1993) both noted that there were no significant gender differences observed in their studies. Whereas, White & Maisey (1997) did not mention any significant difference between genders in their studies.

Computer-Based Assessment

Nichols (1997, May) found that balance retraining with postural force platform biofeedback can address each of the components of steadiness, symmetry, and dynamic stability. Nichols (1997, May) suggests that force platform biofeedback may facilitate improvements in postural steadiness through activities that require maintenance of the center of force (COF). Nichols (1997, May) wrote that on the force platform, the COF is depicted by a cursor on a computer screen and the cursor is to be maintained within a narrow target or within a narrow area screen. As the cursor moves, the subject is to transfer their weight on the force platform to follow the cursor while maintaining equal weight distribution. Nichols (1997, May) describes this weight shifting an activity to encourage stance and stability by maintaining the COF in the middle of the computer screen. Nichols (1997, May) found that biofeedback is what retrains postural steadiness. Lewis M. Nashner (1998, April) on a web site www.onbalance.com parallels Nichols (1997, May) by suggesting force platforms such as the Balance Master can be used in therapy design and related biofeedback training to "enhance the balance retraining process" (p. 2). Nashner (1998, April) also said that the, "clinical value of Balance Master assessment information has been demonstrated in controlled clinical trials. For example, the assessment information has been used to document the superiority of customized balance retraining programs over exercise generic programs" (p. 2). Nichols, Miller, Colby, & Pease (1996) and Rose & McKillop (1998) found that the reliability of the New Balance Master was good to excellent in a study that included administrations of all mobility tests to all subjects.

Summary

There are a number of studies and published literatures that focuses on clinical applications, technology assessment and posturographic evidence, as well as physiological impairments associated with slips and falls. Additionally, there are a number of studies and published literature on protective ensembles being field-tested using anthropeometric and physiological tests for comfort, freedom of motion, agility and heat stress. However, none of these publications or academic literature suggested that protective ensembles could attribute to slips and falls in firefighters who have no apparent sensory deficits, nor do any of these publications or academic literature reviews suggest using clinical applications of computer-based assessment as part of their anthropeometric and physiological tests to measure clothing or equipment performance. One assumption that could be hypothesized is the lack of research in the area of firefighter slips and falls, as well as the lack of research in appropriate job-relatedness studies and longitudinal survey analysis of injuries versus COG and balance ability. Nonetheless, Dunn (1994, June) wrote that slips and falls are the number one cause of injury on the fireground and that there is a misconception about firefighters' slips and falls. He even suggested that the slips and falls were a result of physical and emotional stress which makes firefighters vulnerable to falls, as well as "tunnel vision" and/or the "candle moth" syndrome which causes them to block out the surrounding environment causing falls, slips or misjudged jumps.

Before any solutions can be rendered, the next logical step is to survey chief officers to determine their perspectives on slips and falls, their misconception regarding slips and falls, or both. In addition, there needs to be an assessment using computer-based quantitative measures to evaluate firefighters with no apparent sensory deficits wearing station uniforms and compare the results to protective clothing ensembles.

Once completed, this paper will give other chief officers at Osceola County Fire Rescue Department and the City of Orlando Fire Department insight in selecting and procuring the most appropriate protective clothing ensembles. It will also provide the direction in which to start the groundwork for future research.

PROCEDURES

The research procedure used in preparing this paper included a literature review, questionnaires, interviews, research questions, and involved clinical studies. This research explored whether or not protective clothing ensembles block available afferent information from visual, vestibular and proprioceptive that impaired the balance of firefighters. In addition, this paper explored whether or not physiological impairments associated with age impaired the balance of firefighters, and used computer-based assessment to prove or disprove this assumption.

Definition of Terms

Ankle Strategy is used for standing on surfaces firm and long based on the relation to foot length (Horak and Nashner, 1996).

Anthropometric Testing is the measuring of the human body for height, weight and size of components parts for sizing protective clothing ensembles for freedom of motion and flexibility.

Balance is a state in which the body's Center of Gravity (COG) is maintained over the base of support provided by the feet. With the COG over the base of support, the destabilizing influence of gravity can be resisted while actively moving the COG to perform activities such as rising from a chair, reaching, turning, and walking. When the COG deviates beyond the perimeter of the base of support, a step, stumble, reach, or external support is required to prevent a fall.

Base of Support (BOS) is the area within the perimeter of the contact surface between the feet and the support surface. When the feet are placed comfortably apart on a flat surface, the base of support is a nearly square area.

Center of Gravity (COG) is a point or center of the body when located directly above the center of the support area.

Center of Mass (COM) is the theoretical point about which an object pivots in equilibrium.

Force Platform is a platform that is movable in any XYZ direction in the horizontal plane. The device senses force and momentum in three orthogonal directions that is calculated by either the center of pressure, (COP) or by the center of force (COF).

Hip Strategy is large hip movements for rapid accelerations of COM to maintain balance. Head and trunk accelerate in one direction to move the body's COM in the opposite direction.

Limits of Stability (LOS) are the limits of sway radiating in all directions from the centered position which places the COG at the outer perimeter of the base of support. In normal adults standing on a flat, firm surface with feet spaced comfortably apart, the theoretical LOS perimeter forms an ellipse with an AP dimension of approximately 12.5 degrees and a lateral dimension of approximately 16 degrees. An individual's actual limits of stability may be less than the theoretical limits due to deficits such as ankle muscle weakness and/or reduced range of motion. Individual variations in height and foot length also affect the theoretical limits of stability.

Postural Stability in quiet standing is characterized by random antero-posterior and lateral sway motions of the body's COG relative to the fixed base of support. These motions can be expressed as antero-posterior and lateral sway angles relative to the vertical as defined by the orientation of a hypothetical line connecting the COG with the center of the base of support.

Posturography is a test that tells your physician which parts of the balance system you rely on the most and which parts may be giving you problems. This is done by measuring lateral sway with eyes closed to predict both the center of mass (COM) and the base of support (BOS) and the risk of falling.

PRO & SMART Balance Master Systems is a computer-based assessment that provides quantitative analysis and training of patients with balance and mobility problems.

Proprioception is the body's knowledge or the afferent input of joint position sense of its own depth and location in relationship to text. Proprioception can also be described as the depth perception the body has outward.

Proprioceptive refers to the response of the individual to the neuromuscular system regarding the joints position sense to readjust posture and center of gravity to regain balance.

Protective clothing ensembles are the equipment and clothing that firefighters use to enter hazardous and hostile environments for fire suppression and rescue. The ensembles include self-contained breathing apparatus, helmet, boots, bunker gear and gloves.

Sensory conveys impulses from sense organs to the central nervous system to provide information regarding the body's position (balance).

Somatosensory is the body and skeletal muscle stimulation of touch to provide information to the central nervous systems regarding the balance.

Vestibular is the body's perception of motion to maintain balance through vestibular hair and nerve cells. Vestibular systems use the fluid-filled tubes and canals in the inner ear to sense imbalance, as well as information received from the visual system and the proprioceptive system to maintain balance.

Vision is one of the three systems that maintain balance. The visual system becomes more dominant when the vestibular system becomes impaired.

Research Methodology

Literature Review

The research was historical research in that a literature review of academic publications was conducted to understand the coordination of balance, sensory systems in the control of balance, clinical application of balance, technological assessment of balance, posturographic evidence regarding balance and slips and falls, physiological impairments associated with balance and slips and falls, and computer-based assessment to measure balance. The historical research was initiated at the National Fire Academy (NFA) Learning Resource Center (LRC), and continued with the academic publications at the University of Central Florida library in Orlando, Florida. An additional literature review was conducted on the Internet, using search engines, to explore balance.

The literature review targeted academic research publications and trade journals that explored the physiological impairments associated with age, computer-based assessment to learn strategies in maintaining balance, and limitations and deficiencies of computer-based assessment to learn strategies in maintaining balance. The literature review also examined current clinical applications and assessment methods to determine the reliability and validity of computer-based assessment.

Interview

A personal interview was conducted with Anna Evans, Physical Therapist, Plantation Bay Rehab Center, 401 Kissimmee Park Road, St. Cloud, Florida. The purpose of the interview was to gain background knowledge and significant information on balance and any visionary thoughts on using computer-based assessment to provide accurate information that could be related to firefighters' performance capabilities while wearing protective clothing ensembles. The interview questions are listed in Appendix (A). The personal communication is included in the Literature Review section of this research paper.

Instrumentation

The instrument used in this research consisted of a demographic sheet (Appendix D) and a two-part questionnaire. A cover letter was attached to each survey (Appendix B - Osceola, Appendix C - Orlando). The cover letter explained the purpose of this research and how the results of the survey would be utilized. It encourages cooperation and confidentiality and offered a copy of the summary results if desired.

The survey questionnaire appears in its final form in Appendix (E). The questionnaire was administered to chief officers during a mutual aid meeting in Osceola County. Also, the questionnaires were given to chief officers while on duty at the City of Orlando Fire Department. The chief officers were given an explanation as to why the questionnaire was being presented, and each chief officer was directed to complete the questionnaire as described in the directions at the top of each part of the questionnaire. Upon completion, the surveys were collected and put in an envelope to be used to analyze the data once the target group was surveyed. No chief officer was permitted to take the questionnaire from the survey room, nor were they permitted to fill it out later and return it to this author.

Questionnaire Procedure

Part I of the questionnaire requested that each chief officer (the respondent) to check the change-in-support strategies that the respondents may have seen firefighters use on emergent and non-emergent incidents.

Part II of the questionnaire requested what methodologies for purchasing protective clothing ensembles were used by the respondents. Additionally, the questionnaire requested visioning information from chief officers regarding visionary, innovative methodologies for the selection or purchasing of protective clothing ensembles that could be implemented now to provide the best information to date on the affect of new equipment and protective clothing ensembles on balance and safety. Finally, they were asked about their perceived barriers for using computer-based assessment to elucidate how protective clothing ensembles affected balance and safety of firefighters.

After each chief officer completed his or her survey, they were thanked for their time and participation.

Clinical Study Test Procedures

The clinical study focused on the clinical applications and efficiency of the Pro Balance Master system to compare firefighters' balance in station uniforms to their balance in protective clothing ensembles. A. Evans, P.T., D. Lameier, P.T. and N. Varveris, P.T. conducted the clinical study at Plantation Bay Rehab Center, 401 Kissimmee Park Road, St. Cloud, Florida. The purpose of the clinical study was to determine the following:

1. The effect of protective clothing ensembles on balance.
2. The change in COG and limits of stability because of the protective clothing ensembles.
3. Measurement of the body's performance in the two conditions to identify potential hazardous environments.

Test Subjects

The test subjects were three healthy, male firefighters from moderate to excellent physical fitness with no apparent balance impairments. Subject 1 was a 27 year old male. Subject 2 was a 37 year old male. Subject 3 was a 43 year old male.

Test Conditions

Condition 1: Firefighters with station uniforms.

Condition 2: Firefighters with station uniforms and protective clothing ensembles weighing approximately 45 pounds. The protective ensembles included:

1. Morning Pride bunker clothing, model BRP1407;
2. Ben Franklin 2 Helmet, model BRP; and
3. Scott 2.2A, self contain breathing apparatus, standard bottle, 30.6 pounds.

Test Equipment

The Pro Balance Master was utilized in this clinical study. This state-of-the-art computer-based system is the most advanced balance equipment on the market. It consists of a movable force platform on which one sits or stands and a monitor screen displaying a cursor that represents the COG.

Test Procedure

The subjects completed the following nine (9) balance tests on the Pro Balance Master:

1. Eyes open fixed surface (EO)--standing surface does not move. The subjects were directed to stand as steady as possible for 20 seconds with their eyes open.

2. Eyes closed fixed surface (EC)--standing surface does not move. The subjects were asked to stand as steady as possible for 20 seconds with their eyes closed.

3. Center target (CT)--The subjects were asked to stand in the center target as steady as possible for 20 seconds.

4. Rhythmic weight shift side to side (RWS-R/L). The subjects were asked to follow the circle from side to side while keeping up with its speed. The test is done at 3 speeds; 3 second pace, 2 second pace, and 1 second pace.

5. Rhythmic weight shift front to back (RWS-F/B). The subjects were asked to follow the circle from front to back while keeping up with its speed. The test is done at 3 speeds; 3 second pace, 2 second pace, and 1 second pace.

6. Limits of stability at 75 percent (LOS). The subject were asked to follow the circle into the next highlighted target as quickly as possible, in a straight line and once in the box, to hold the position as steady as possible until the circle returns back to the center target. The circle moves in a predicted sequence from the right to left target.

7. Random Limits of stability at 75 percent (RLOS). The subjects were asked to follow the circle into the next highlighted target as quickly as possible, in a straight line, and once in the box, to hold the position as steady as possible until the circle returns back to the center target. The circle moves in a random unpredictable sequence from target to target.

8. Eyes open sway referenced surface (EO/SS)--standing surface movement matches the degree and amount of sway the subject produces. The subjects are asked to stand as steady as possible for 20 seconds with eyes open.

9. Eyes closed sway referenced surface (EC/SS)--standing surface movement matches the degree and amount of sway the subject produces. The subjects are asked to stand as steady as possible for 20 seconds with eyes closed.

The nine (9) tests were completed under condition # 1 first. After approximately five minutes, the same sequences of tests were completed under condition # 2.

Assumptions and Limitations

The questionnaire had several assumptions and limitations. One assumption was that all chief officers use the same methodology to select and procure protective clothing ensembles. This assumption should not present any problems, unexpected outcomes, or both because the NFPA standard:

1. Provides documentation of protective clothing ensemble performance,
2. Defined minimum comprehensive performance criteria for protective clothing, and
3. Standardized testing protocols and evaluation procedures.

One limitation of the questionnaire used was the open-ended question format. Many of the respondents who completed the surveys were resistant and reluctant to write down answers to the questions. The intent of the open-ended questionnaire format was for the author to gather visionary, innovative methodology for testing protective clothing ensembles that the participants envision their Department purchasing, as well as perceived barriers to testing protective clothing ensembles without artificially inflating or deflating the perception of the respondents.

The questionnaires were limited to a small group of respondents within Osceola County Fire Rescue Department volunteer chief officers and the City of Orlando Fire Department chief officers. A questionnaire distributed nationally may have provided additional information of visionary and innovative methodologies for testing protective clothing ensembles that participants envision their Departments moving to purchase. However, because of the time restraints to complete this paper, a smaller number of respondents were chosen. In addition, because of the small number of respondents sampled, the information may not be considered as representative of all chief officers. Nonetheless, the information obtained was essential to this research.

A limitation with the clinical study was the cost of conducting the computer-based assessment. Because of this, a small subject population was assessed making it difficult to conclude that balance is affected negatively by protective clothing ensembles. Additionally, although the subjects appeared to be healthy and had no apparent physical limitation or impaired balance, they could have had a deficiency in their postural orientation from sensory systems in the visual, somatosensory and vestibular.

Lastly, because of the small population used in the clinical study and the difficulty in expressing the results, the researcher decided to average all three clinical studies. This could be considered artificially inflating or deflating the perception of the results. However, all three individual's test results were within points of each other and the information obtained was essential to this research.

Survey: Definition of Population

The questionnaire was given to 36 chief officers from 12 different departments to analyze their visionary and innovative methodologies for testing protective clothing ensembles. The purpose of the questionnaire was to:

1. quantify the number of chief officers that have seen change-in-support strategies used by firefighters on fireground operations,
2. identify current methodologies used for selection and purchasing protective clothing ensembles,
3. to determine visionary and innovative methodologies for selection and purchasing of protective clothing ensembles, and
4. identify perceived barriers of using computer-based assessment to provide beneficial data on the effect of new equipment and protective clothing ensembles on balance and the safety of firefighters.

Populations of the Survey

The population completing the questionnaire included 12 fire departments and 30 chief officers from the rank of District Chief and higher.

Collection of Data

There were 30 questionnaires completed out of a possible 36 for an 83 percent response rate.

RESULTS

These results review answers to the research questions and results of the surveys and questionnaires.

Answers to Research Questions

Research Question 1. What deficiencies are encountered while wearing protective clothing ensembles in order to position one's center of gravity (COG) over the base of support (BOS) in a given sensory environment as compared to street clothing? Historical research and literature reviews provided no information to address this question. Because of the lack of research, it was believed that generalizability theory would have to be used to determine deficiencies encountered while wearing protective clothing ensembles. However, during the historical research and literary reviews, the Pro Balance Master assessment information provided strong evidence of reliability during the biofeedback. Therefore, clinical studies were conducted using the Pro Balance Master assessment information to obtain an answer.

Protective clothing ensembles displaced the center of gravity (COG) such that the subject was farther from center. This was documented in Test # 1, # 2, # 8, and # 9 where the COG was displaced more due to the ensembles as compared to street clothing. Also, protective clothing ensembles decreased proprioceptive and somatosensory input to the central nervous system, thus decreasing balance and increasing instability in challenging environments. This was evident when comparing the results of the five sensory tests under condition # 1 to condition # 2. As the difficulty level increased, the subjects' sway increased in each condition, as well as increased in condition # 2 compared to # 1. Thus, protective clothing ensembles did contribute to decreased stability in the subjects. Additionally, two of the subjects had a significant and abnormal increase in sway with the protective clothing ensembles and eye closed in test # 2 compared to station uniforms in the same test. This could be attributed to the possibility of visual dependence, as well as decreased proprioceptive input from fire and rescue boots and possible vestibular system involvement. In condition # 2, when vision was eliminated and proprioception was diminished (Test # 9), two of the subjects performed the poorest in maintaining balance while wearing the protective clothing ensembles, thus, indicating that if a firefighter had decreased vestibular system input, protective clothing ensembles will magnify instability when placed in such sensory environments where visual and proprioceptive input is poor because of the fire and rescue boots and the self contained breathing apparatus mask. Therefore, protective clothing ensembles do create an additional challenge to the stability of firefighters, and increase the use of hip strategies to prevent falls as compared to station uniforms where ankle strategies were effective in maintaining balance.

Research Question 2. Do physiological impairments associated with the firefighters' age affect one's center of gravity (COG) over the base of support (BOS) in a given sensory environment? As mentioned above, the literature reviews did not address this question regarding physiological impairments associated with the firefighters' ages. However, it was found that several authors, such as Sabelman, Gadd, Chesney, et al. (1994), Whipple, Wolfson, Derby, Singh, & Tobin (1993), and White & Maisey (1997) suggest postural stability is a physiological impairment effected by aging. These authors used various motion tasks to analyze their responses to the control of balance perturbations and have conducted several clinical studies with young and older populations. The Balance Master assessment information and the accelerometric system analyzed the motion tasks and produced similar results. The motion tasks were walking, quiet standing with eyes both open and closed, walking up and down three steps, and rising from and sitting in a chair. The Balance Master provided quantitative measures of center of gravity (COG) and limits of stability (LOS) sway referenced to an age-matched normative data base. Sabelman, Gadd, Chesney, et al. (1994) noted that vertical acceleration peaks were higher for the older group when ascending and descending stairs. Sabelman, Gadd, Chesney, et al. (1994) hypothesized that this was possibly due to stiffening of intervertebral discs in the elderly. In addition, Sabelman, Gadd, Chesney, et al. (1994) suggested that hearing and vision abilities decline with age and impaired the balance in the study population. Sabelman & Winograd (1999, July) paralleled White & Maisey (1997) adding that, "the sense of balance declines with age to combined vestibular, proprioceptive and visual losses, resulting in impaired mobility and increased risk of injurious falls" (p. 1). Whipple et al. (1993) suggested limit of stability (LOS) distances decreased and eyes closed sway increased with age. All Balance Master measures showed the expected strong changes with age. Sabelman et al. (1994) and Whipple et al. (1993) both noted there were no significant gender differences observed in their studies. Whereas, White & Maisey (1997) did not mention any significant difference between genders in their studies.

Research Question 3. What are the advantages of computer-based assessment in learning firefighters' strategies in maintaining balance? According to several of the authors, such as Nashner (1998, April), Nichols (1997, May) and Rose & McKillop (1998) analysis of computer-based assessment provided a key component of information used to customize training programs for patients with impaired balance, as well as strengthen proprioception, vestibular, and visual systems. Computer-based assessment has been documented as having good to excellent reliability "providing therapy design, as well as center of gravity biofeedback and related biofeedback training devices to enhance the balance retraining process" (Nashner, 1998, p. 2). In the literature review, reliability, sensitivity and validity have characterized the accuracy of computer-based assessment. Additionally, computer-based assessment could prove beneficial to the fire service in the following ways:

1. To provide balance and stability data to serve as a baseline during therapy treatment in case of any work related injury.
2. It could be used as a screening tool to identify strengths and weaknesses in balance.
3. To provide information regarding potential environmental conditions that may be a higher risk for falling and injuries.
4. As a preventative tool to strengthen identified weak balance areas, such as proprioception, vestibular and visual system.
5. To provide beneficial data on the effect of new equipment and protective ensembles on balance and safety, prior to the purchase of such equipment.
6. Provide real-time analysis and feedback that can be applied to prevention of injuries, training, or both.

Research Question 4. What are some of the limitations and deficiencies of computer-based assessment in learning firefighters' strategies in maintaining balance? Force platforms and accelerometry were the two types of computer-based assessment mentioned in the literature reviews. The literature reviews summarized computer-based assessment using force platforms as state-of-the-art and provided reliable quantitative analysis of balance problems. In addition, very few of the literature reviews discussed limitations, deficiencies, or both. However, for patients with mild involvement of balance problems, the "traditional force platform biofeedback may facilitate improvements in gait speed and cadence but may not address asymmetry" (Nichols, 1997, May, p. 5). Additionally, although computer-based force platforms measures of steadiness have been reported to be reliable and valid, "units that use center of force [COF] measures have been found to be more reliable that those that use center of pressure [COP] measures" (Nichols, 1997, May, p. 3). Accelerometry has also been assessed as reliable and valid. Nonetheless, a deficiency found with accelerometry computer-based assessment is that it measures the tilt of the head and the direction of motion cannot be determined from the acceleration magnitude. Thus, "tilt of the head was assumed to be linear " (Sabelman, 1997, p.3). Additionally, "the assumption of linear head tilt is only partial correction for acceleration so that velocity and displacement can be calculated without artifactual 'head motion' after the subject has reached vertical stance" (Sabelman, 1997, p. 4). Also, software for extracting sway angle is currently being written and will be installed in the new systems, along with software to reduce artifacts due to human movement.

Research Question 5. Does computer-based assessment replicate the reality of firefighters' strategies in maintaining balance? Several authors such as Nichols (1997, May), Nashner (1998, April), Nichols, Miller, Colby & Pease (1996), and Rose & McKillop (1998), as well as personal communications with A. Evans (2000, January 4) suggest that force platform biofeedback, a computer-based assessment, could replicate the reality of different strategies in relation to their environment. Nichols (1997, May) also suggested that weight shifting on a force platform would encourage stance and stability that could replicate the reality of maintaining balance through the use of either ankle or hip strategies. This was also confirmed by the clinical studies conducted at Plantation Bay Rehabilitation Center that demonstrated firefighters use ankle strategies while wearing station uniforms and then change to hip strategies while wearing protective clothing ensembles as the environment changed. This computer-based assessment, the Pro Balance Master, replicated the reality of different strategies in relation to the environment that firefighters would have to go through. Additionally, the Pro Balance Master indicated that firefighters are under more stress and challenge while wearing protective clothing ensembles than street clothing. These clinical studies also showed increased use of hip strategies to maintain balance and prevent falls. In some instances, this was shown to be approximately four times greater.

Research Question 6. Will computer-based assessment influence firefighters in learning their strategies to maintain balance? During the literature review, computer-based assessment was attributed to learning strategies to maintain balance as seen in clinical studies conducted by Quinn (1999, July). Also, clinical studies conducted by Laskowski, Newcomer-Aney, & Smith (1997) indicated that proprioception can be improved through training. Their studies also indicated that afferent input of joint position sense and reactive efferent output to significantly reduce postural sway could be learned through balance strategies in both static and dynamic environments. Additionally, the clinical study conducted at Plantation Bay Rehabilitation Center indicated that it was possible for firefighters wearing protective clothing ensembles to learn strategies to maintain balance in hazardous environments, and that firefighters who have balance impairments could learn strategies to maintain balance in a day-to-day environment.

Results of the Survey

Demographic Characteristics for Osceola County Fire Rescue Department

Twenty volunteer chief officers of the nine fire districts within Osceola County completed the survey. Most respondents reported 1-5 and 16-20 years of service representing 38 percent and 33 percent respectively.

The majority of the sample population included assistant chiefs (52 percent), followed by deputy chiefs (5 percent) and finally, fire chief officers (43 percent).

Males made up 76 percent of the population. The majority of the sample group was between 31-45 years of age.

One hundred percent (100 percent) of the survey group was Caucasian. Five percent (5 percent) of those cited Hispanic heritage.

Additional demographic information can be found in Appendix F.

Demographic Characteristics for the City of Orlando Fire Department

Ten chief officers from the City of Orlando Fire Department completed the survey. Most respondents reported between 21 and 25 years of fire service.

The majority of the sample population included district chiefs (77 percent), followed by assistant chiefs (23 percent).

Males made up 88.5 percent of the population. The average age of the sample group was between 35-45 years.

Eighty-eight and one half percent (88.5 percent) of the survey group was Caucasian, eleven and one half percent (11.5 percent) of the survey group was African-American.

Eleven and one half percent (11.5 percent) of the population cited Hispanic heritage.

Additional demographic information can be found in Appendix G.

Most Significant Demographic Data

The most significant demographic data of the 83 percent chief officers surveyed, whether volunteer or career, is that they only had a high school education, some college, or both. Table 1 below shows the responses based on department type and the corresponding response percentage.

Table 1
Number of Responses Based on Education

EDUCATION	Career	%	Volunteer	%
High School	0	0%	12	60%
Some College	7	70%	4	20%
College--Associate of Arts/Associate of Science	1	10%	2	10%
College--Bachelor of Arts/Bachelor of Science	1	10%	1	5%
College--Graduate Degree or Graduate Classes	1	10%	1	5%

Part I. The Instrument

Part I of the questionnaire requested that each respondent check the change-in-support strategies that they have seen firefighters use on emergent and non-emergent incidents. The most significant answer was slips and falls. Table 2, below, lists the responses based on department type and the corresponding response percentage.

Table 2
Change-in-Support Strategies Observed on Firegrounds

CHANGE-IN-SUPPORT	Career	%	Volunteer	%
Compensatory stepping movements	1	10%	0	0%
Rapid stepping to recover balance	1	10%	1	5%
Grasping movements of the limbs	0	0%	0	0%
Rapid volitional arm movements	1	10%	0	0%
Slips	3	30%	9	45%
Falls	4	40%	8	40%
Missed jumps	0	0%	2	10%
Other	0	0%	0	0%

Part II of the questionnaire requested information concerning what methodologies for purchasing protective clothing ensembles were used by the respondents. Additionally, the questionnaire requested visioning information from chief officers regarding visionary and innovative methodologies for the selection or purchasing of protective clothing ensembles that could be implemented now to provide the best data on the affect of new equipment and protective clothing ensembles on balance and safety. The most significant answer was human mediated evaluation by performing physical task, such as bending, rotating and flexing. This answer was followed by firefighters wearing the ensembles into live fires in either an abandoned structure or using a training facility's burn building. Table 3 lists some of the respondents' selected responses.

Table 3
Selected Responses

Methodology for purchasing protective clothing ensembles	Visionary, innovative methodologies for selection or procurement	Fire service providing the best protective clothing ensembles
Field-testing for comfort and freedom of mobility	Use knowledge and concepts from computers to investigate protective clothing ensembles	Use the performance criteria and results provided by NFPA
Trial testing in live fires	Provide movement analysis not observable with the eye	
No test--mandated to use the protective clothing ensembles provided by the department	Computer-based assessment to develop protective clothing ensembles	

The third question inquired about perceived barriers for using computer-based assessment to elucidate how protective clothing ensembles affected balance and safety of firefighters. The answer most often given was the cost of computer-based assessment, as well as the lack of needed skills and knowledge to use computer-based assessment.

Results of the Clinical Study

Graph A (Appendix H) represents the subjects' sway, stability, or both and COG position in tests 1-3 (EO, EC, CT) in condition # 1 compared to condition # 2.

Test # 1: With eyes open and on a fixed surface, the subjects' sway or stability did not change when protective clothing ensembles were put on (0.08) compared to station uniforms (0.08). However, the subjects' COG position did shift backward significantly with protective clothing ensembles on (21.7 percent LOS) compared to station uniforms (16.4 percent LOS).

Test # 2: Comparing condition # 1 and # 2 in this test revealed a significant difference in the subjects' sway. Comparison of subjects' results under test # 1 and test # 2 demonstrate a two fold increase in sway with eyes closed in test # 2 (0.16) compared to eyes open in test # 1 (0.08) under condition # 1, and a three fold increase (from 0.08 to .28) under condition # 2. The subjects showed a backward shift in their COG under condition # 2 (17.6 percent) compared to # 1 (6.2 percent) in this test because of the self-contain breathing apparatus, respectfully.

Test # 3: With visual feedback in this test, it is evident that the subjects' sway decreased by half under condition # 2 (0.04) compared to condition # 1 (0.09). The subjects' position was also most centered in this test (0.8 and 0.6) as compared to test # 1 and test # 2.

Graph B (Appendix I) represents the subjects' sway/stability and COG position in test 1-3 (EO, EC, CT) compared to normative data in condition # 1 and condition # 2.

Test # 1: With eyes open and surface fixed, the subjects' stability is less than the average in both condition # 1 and # 2, as evident by ranking only in the 29.5 percent, and 24.6 percent respectively, relative to the normal population in his age and height. The subjects' COG position was about average (43.6 percent) in condition # 1, however less than average in condition # 2 (22.6 percent).

Test # 2: With eyes closed and a fixed surface, the subjects stability was still less than average, but within normal range (21.0 percent) under condition # 1. Under condition # 2, however, his stability was in the abnormal range (0.5 percent). The COG position was more centered in both conditions in this test.

Test # 3: With visual feedback, the subjects' stability under condition # 1 was significantly less than average (10.8 percent). However, in condition # 2, they were more stable than the average population in their age and height group (60.3 percent). The COG position was more centered in both conditions in this test as compared to tests # 1 and # 2.

Graph C (Appendix J) demonstrates the ability to keep up with a set pace and change directions quickly under condition # 1 compared to # 2 at three speeds.

Test # 4: The subjects were able to keep up with a faster pace much better than a slower pace in both condition # 1 and # 2. However, under condition # 2, they were able to do so much more smoothly and with less path sway or unsteadiness as compared to condition # 1.

Test # 5: The subjects demonstrated the same ability to move better and steadier in a faster speed under condition # 2. Comparing test # 4 and # 5, it can be determined that the subjects are more comfortable moving side to side rather than from the front to back position.

Graph D (Appendix K) demonstrates the standard limits of stability test at 75 percent in condition # 1 compared to condition # 2.

Test # 6: Overall, the subjects' path sway was less under condition # 2 compared to condition # 1 in all directions except transition to right forward (2) and right side (3). The subjects' sway in the different targets was less under condition # 2 as compared to condition # l except in right back (4) transition. The subjects' average limit of stability is approximately 64 percent under both condition #1 and # 2.

Graph E (Appendix L) demonstrates actual sway/stability and COG position under two sensory tests, 7 and 8, eyes open sway referenced surface and eyes closed sway-referenced surface under condition # 1 and # 2.

Test # 7 & 8: In these test, the subjects swayed about twice as much under condition # 2 (0.3) compared to condition #1(0.13). Under condition # 1, the subjects' sway, (0.13) was approximately 1.6 times greater than their sway under condition #1 in test # 1 (0.08). Under condition # 2, the sway (0.3) was close to four times that of condition # 2 in test # 1 (0.08).

Test # 9: In this test, the subjects' sway (0.37) was almost two times greater than their sway under condition # 1 in test # 2 (0.16). Under condition # 2, the sway (1.35) was five times greater than condition # 2 (0.28) in test # 2.

Graph F (Appendix M) demonstrates stability under three sensory tests: # 2, # 8, and # 9 in condition # 1 and # 2.

Averaging the three sensory tests, the subjects were 6 percent more stable under condition # 1 compared to condition # 2. However, there is a significant decrease in stability under condition # 2 in test # 8 and # 9, compared to condition # 1 in the same tests.

Graph G (Appendix N) demonstrates stability and type of strategy used to maintain that stability under condition # 1 and # 2.

Clearly, all three of the subjects were under more stress and were more challenged in condition # 2 compared to # 1, as is evident by the increased use of hip strategies to maintain balance and prevent falling.

DISCUSSION

It is the consensus from questionnaires and the opinion of those interviewed that it is common to see firefighters using stepping or grasping movements of the limbs, as well as slipping, falling, or both on the fireground under emergent and non-emergent conditions. The respondents did not relate these incidents to the possibility of impaired balance due to the protective clothing ensembles, or the possibility of physiological impairments due to the firefighters' ages. It was also the consensus from questionnaires and the opinion of those interviewed that some other form of testing is needed to augment existing testing criteria for protective clothing ensembles regarding their effect or limitations on balance. The main concern of several chief officers responding to the questionnaire and interview was that they seldom have a chance to test protective clothing ensembles because of the costs to conduct the testing. If the respondents had conducted some form of testing protective ensembles, the most common method was to field test the equipment by performing physical tasks, such as bending, rotating and flexing. This was followed by a pencil and paper checklist evaluation of their evaluations of the protective ensembles. The respondents felt that this type of evaluation was more for the comfort and freedom of mobility of the protective clothing ensembles than for any other reason. Several of the respondents did not feel comfortable with this type of evaluation because it only tested for comfort and flexibility.

A second method of testing was to have firefighters wearing the selection of protective clothing ensembles to be evaluated enter live fires in either an abandoned structure or burn training facility. The goal of the live fire was to provide realistic and effective evaluation criteria and performance based on the firefighters' opinion of how the protective clothing ensembles felt under live fire conditions. One problem with this type of evaluation is that it could be considered subjective instead of quantitative. Also, some suggested that live fire evaluations are not the same as those experienced in the real world, and the experience will give those evaluating the protective clothing ensembles a false impression regarding the lack of debris in pathways, such as in real environments to challenge mobility.

Academic literature and trade journal literature reviews indicated that physiologic and anthropometric test were performed on protective clothing ensembles. These tests were to evaluate the ensembles in terms of heat and flame protection, waterproofness, and comfort. However, none of the testing procedures discussed in the literature review addressed the issue of balance impairment while wearing protective clothing ensembles, or if the ensembles blocked available afferent information from visual, vestibular and proprioceptive inputs. The anthropometric tests mentioned in literature reviews were regarding the measuring of the human body for height, weight and size of components parts for sizing protective clothing ensembles for freedom of motion.

Statistics in the academic literature and trade journal literature reviews espoused that a majority (60 percent) of falls happen on the same level resulting from slips and falls. Many of these slips and falls are due to poor lighting or the failure to detect changes in the environment, along with distractions in the environment, or both. However, literature reviews indicate these are not the only reasons for slips and falls, and those assumptions lead to a one-dimensional view or investigation of the slips, falls, or both. Nonetheless, slips and falls can result for numerous reasons and can be seen as "changes in support strategies, involving stepping or grasping movements of the limbs" (Maki & McIlroy, 1997, p. 77). Academic literature reviews also suggest that automatic responses control balance through postural orientation responses and voluntary movements that restore the limits of stability (LOS) and maintain the center of gravity (COG). Restoring equilibrium or maintaining the COG is possible through ankle and hip strategies, or a combination that uses sensory detection through one or all of the three systems: the visual, vestribular and proprioceptive. External weight, such as protective clothing ensembles, repositions the COG while performing a task or simply standing still. Additionally, academic literature and trade journal literature reviews, as well as research study reviews suggested that the application of computer-based assessment and training would benefit participants through biofeedback to improve efficiency of performing tasks, as well as document compliance, quality and volitional control. Computer-based biofeedback also displays errors that participants may unconsciously perform while executing different task, and when the participants are encumbered. For instance, to show the shifting from the use of normal ankle strategies to that of hip strategies.

The clinic studies found that protective clothing ensembles displaced the center of gravity (COG) so that the subjects were further from center. This was noted in Test # 1, # 2, # 8, and # 9. Protective clothing ensembles decreased proprioceptive and somatosensory input to the central nervous system, thus decreasing balance and increasing instability in challenging environments. In the five sensory tests performed while wearing station uniforms (condition # 1) it was compared to wearing protective clothing ensembles (condition # 2), was evident that as the difficulty level increased, the subjects' sway increased while in each condition, as well as increased in condition # 2 as compared to condition # 1. Thus, protective clothing ensembles did contribute to decrease stability in the subjects (Graph H, Appendix O). Also, there was a significant and abnormal increase in sway with protective clothing ensembles and eyes closed, such as in a smoke filled environment in Test # 2 compared to station uniforms in the same test. This could also be secondary to visual dependence, as well as decreased proprioception input from heavy boots and a possible vestibular system involvement. Additionally, while wearing protective clothing ensembles, and when vision was eliminated (Test # 2) and proprioception was diminished (Test # 9), the subjects performed the poorest to maintain balance. This indicated that for firefighters with decreased vestibular system input, wearing protective clothing ensembles will magnify instability when placed in such sensory environments where visual and proprioceptive input is poor. The clinical studies indicated protective clothing ensembles do create an additional challenge to the stability of firefighters, and cause an increased use of hip strategies to prevent falls.

In addition, the computer-based assessment and biofeedback can provide baseline data on balance and stability that could be used in the event of any work related injury. They could also be used as a screening tool to identify strengths and weaknesses in balance. Computer-based assessment can also provide information regarding potential environmental conditions that may create a higher risk for falling, higher risk for injuries, or both. It could be used to strengthen identified weak balance areas such as proprioception, vestibular and visual systems. Lastly, computer-based assessment could provide beneficial data on the effect of new equipment and protective clothing ensembles on balance and safety prior to procurement of such equipment.

This researcher argues that in order to properly evaluate protective clothing ensembles effects on balance, the use of computer-based assessment will be required.

RECOMMENDATIONS

In today's fire service, due to the variety of protective clothing ensembles available, selecting and procurement can be a difficult process. The NFPA standards established performance criteria that reduce many limitations for firefighters wearing the protective ensembles. However, NFPA does not have any performance criteria for determining if protective clothing ensembles impair the balance of firefighters other than field tests that are subjective. Nonetheless, this research has identified the need for computer-based assessment for analysis. In addition, the opportunity for computer-based application is exceptionally high at the present time with technology evolving at exponential rates.

Because of the current cost of computer-based assessment and biofeedback, King's Point Volunteer Fire Department, as well as the Osceola County Fire Rescue Department and the City of Orlando Fire Department will not be able to utilize this application for evaluating balance as it relates to protective clothing ensembles. Eventually, the cost of computer-based assessment and biofeedback will decrease, which will allow chief officers to evaluate protective clothing ensembles before selection and procurement. However, until then, there is still the tremendous need to effectively evaluate protective clothing ensembles' effect on the balance of firefighters during emergent and non-emergent incidents. The recommendation of this researcher is for an agency, such as the National Fire Academy (NFA) or the National Fire Protection Association (NFPA), to do further research using computer-based assessment, and to establish performance criteria, which includes computer-based assessment, to evaluate protective clothing ensembles and their effect on the balance of firefighters. In addition, this research will be submitted to the NFPA Technical Committee through the public proposal process. Although this research indicated that balance is affected negatively with protective clothing ensembles, because of the small subject population it is difficult to conclude that balance is affected negatively by protective clothing ensembles, or if visual, vestibular, proprioception, and somatosensory inputs are being blocked by protective clothing ensembles. Nonetheless, this research demonstrated that protective clothing ensembles block available afferent information from visual, vestibular and proprioceptive inputs which puts firefighters at a higher risk for falls or balance related injuries when placed in dark and unfamiliar situations with an uneven surface.

REFERENCES

Angle, J.S. (1999). *Occupational safety and health in the emergency services*. Albany, NY: Delmar Publishers.

Duffy, R., Sawicki, J.C., & Beer, A.R. (1985). *Project fires: Firefighters integrated response equipment system*. Washington, DC: International Association of Firefighters.

Dunn, V. (1994, June). Slips, falls and missed jumps. *Fire House, 19*, 20-21.

Firefighting fabrics. (1997, October). *Fire & Rescue, 14*, 16-18.

Givens, D. (1999, October 15). *Balance*. [On-line serial]. Available Internet: www.webco.net/apda/physical/balan.htm

James, C.R. (1998, November 31). *ESS 3301 mechanical kinesiology*. [On-line serial]. Available Internet: www.hper.ttu.edu/james/ESS percent203301/cog.htm

Horak, F.B. (1991). *Assumptions underlying motor control for neurological rehabilitation.* Step Contemporary Management of Motor Control Problems. APTA. Alexandria, VA: Author.

Horak, F.B. & Nasher, L.M. (1986). Central programming of postural movements: Adaptations to altered support surface configurations. *Journal Neurophysiol, 55*, 1369-1302.

Horak, F.B. , & Woollacott, M. (1996). *Balance disorders and falls in the elderly*. Symposium conducted at the meeting of Physical Therptist, Miami, FL.

Kerwood, S.D. (1997, March). *A five year analysis of occupational injuries for the Orange County Emergency Services District No.1*. Unpublished research paper, National Fire Academy, Emmitsburg, MD.

Leibowitz, H.W. & Shupert, C.L. (1985). Spatial orientation mechanisms and their implications for falls. *Clinics in Geriatric Medicine, 1*, 571-580.

Laskowski, E.R., Newcomer-Aney, K. & Smith, J. (1997, October). *Refining rehabilitation with proprioception training: Expediting return to play*. [On-line serial]. Available Internet: www.physsportsmed.com/issues/1997/10oct/laskow.htm

Maki, B.E. & McIlroy, W.E. (1997). The role of limb movements in maintaining upright stance: The change-in-support strategy. *Physical Therapy, 77*.

Mayo Clinic (1999, February 22). *Vestibular rehabilitation program Mayo Medical Center, Rochester, MN*. [On-line serial]. Available Internet: http://www.mayo.edu/vest-rehab/

Miller, B.C. (1999, September 11). *Investigating slips and falls: The complex dynamics behind simple accidents*. [On-line serial]. Available Internet: http://www.safety-engineer.com/complex.htm

Nashner, L.M. (1998, April). *Balance Master systems: Summary of key clinical findings in the literature*. [On-line serial]. Available Internet: www.onbalance.com

Nashner, L.M. & McCollum, (1985). The organization of human postural movements: A formal basis and experimental synthesis. *Behavior Brain Science, 8*, 135-172.

Nichols, D.S. (1997, May). Balance retraining after stroke using force platform biofeedback. *Physical Therapy Journal, 77*, 553-558.

Nichols, D.S., Miller, L., Colby, L.A., & Pease, W.S. (1996). Sitting balance: Its relations to functions in individuals with hemiparesis. *Arch Physical Medical Rehabilitation, 77*, 865-869.

Oddsson, L.I.E. (1990). Control of voluntary trunk movements is man mechanism for postural equilibrium in standing. *Acta Physiol Slan,* (Suppl. 595), 140.

______. (1999, July). *Risk factors of muscle injury and falls related to load handling technique*. [On-line serial]. Available Internet: http://nmrc.bu.edu/iap/script/Summary/eleven.html

______. (1999, November). *The problem of specificity in the training process of vertical jumping*. [On-line serial]. Available Internet: http://nmrc.bu.edu/iap/script/Summary/one.html

Oddsson, L.I.E., Persson, T., Cresswell, A. & Thorstensson, A. (1999, July 31). *Why do balance perturbation during lifting present hazard to the spine?* [On-line serial]. Available Internet: http://nmrc.bu.edu/iap/script/Summary/six.html

Pagels, T. (1987, May). Firefighter injuries and deaths – the big question – why? *Rekindle,16*, 9.

Quinn, E. (1999, July). *Balance training for improved sports performance*. [On-line serial]. Available Internet: http://sportsmedicine.about.com/library/weekly

Rose, D.J. & McKillop, J. (1998). *Assessment of balance and mobility functions: a reference study based on the Balance Master*. NeuroCom, Inc.

Runge, C. F., Shupert, C. L., Horak, F. B., & Zajac, F. E. (1996). *Coordination of balance - selection of control strategies*. [On-line serial]. Available Internet: http://guide.stanford.edu/96reports/96mech7.html

Sabelman, E. E., Gadd, J., Chesney, D., Merritt, P., Winograd, C., Kinney, D., Troy, B., & Gabrielli, S. (1994). *Rehabilitation R&D center progress report*. [On-line serial]. Available Internet: http://guide.edu/Publications/clin3.html

Sabelman, E.E. & Winograd. (1999, July). *Reliability and validity of accelerometric gait*. [On-line serial]. Available Internet: http://guide.stanford.edu/Projects/clin08.html

Stull, J.O. (1999, July). Helmets, hoods and gloves for protecting firefighters. *Fire and Rescue,* 57-61.

United States Bureau of Labor Statistics. (1999, February). *Highest rate for injures*. [On-line serial]. Available Internet: http://wugovinfo.mininglo.com/culture/susgovinfo/gi/dynamic/.offsite.htm://www:bls.gov

United States Fire Administration (1993, September). *The minimum standards on structural firefighter protective clothing and equipment: A guide for fire service education and procurement*. (Publication FA-137). Washington, DC: Federal Emergency Management Agency, United States Fire Administration.

______. (1995). *Fire in the United States* (10th ed.). Washington, DC: Federal Emergency Management Agency, United States Fire Administration.

Vestibular Disorders Association. (1999, November). *Vestibular disorders: an overview*. [On-line serial]. Available Internet: http://www.teleport.com

Volunteer Fireman's Insurance Service. (1996). *Workers' compensation claims*. Unpublished raw data.

Wheller, M. (1997, November). Fall guys: A researcher in ergonomics asks elderly to volunteer to take a trip (research on accidental falls). *Discover Magazine, 18*, 120.

Whipple R., Wolfson L., Derby C., Singh D. & Tobin J. (1993). Altered sensory function and balance in older persons. *Journal of Gerontology, 48,* 71-76.

White, L. & Maisey, J. (1997). *Proprioception: Why do elderly people fall? And preventative measures*. [On-line serial]. Available Internet: http://science.canberra.edu.au/hbms/hpa3student/georgina/jo-ietilia6.html

Zimmer, C. (1996, February 1). *Circus science: No one can ignore the laws of physical world, least of all the performers who seem to flout them*. [On-line serial]. Available Internet: http://www.elibrary.com/s/edumark/getdoc.cgi/id=145675377x127y58653wO&OIDS

Appendix A
Personal Interview Questions

Due to the variety of protective clothing ensembles available, selecting and procurement can be a difficult process. The NFPA standards established performance criteria that reduce many limitations. Although manufacturers show evidence of compliance with NFPA, many times there may be specific areas of protection not covered in available specifications and your Department may field-test the ensembles to determine performance criteria. As a visionary, what are some innovative testing methodologies that could be used for selecting or procurement of protects?

Appendix B
Survey Cover Letter for Osceola County

All Volunteer Chief Officers
Osceola County Fire Rescue Department

Dear Fellow Chief Officers:

As a volunteer for Osceola County, you can provide me with information that can be used to research the need for computer-based assessment regarding selection, design or purchase of protective clothing ensembles. Presently I am enrolled in the National Fire Academy's Executive Fire Officer Program, and as a part of my studies, I am required to do a research paper. The project will focus on computer-based assessment for selecting, designing or purchasing protective clothing ensembles. Once completed, the volunteer fire chiefs and training personnel will review the results of this study.

Your full participation in the study will involve: (1) your completion and return of the enclosed two part questionnaire, and (2) your completion of the demographic background sheet.

For confidential reasons, names will not be needed or required. I will be the only person who will be able to link your name with the information you provide. After all my statistics have been compiled and analyzed, the demographic sheets will be separated from the questionnaire.

In order to insure that the results are valid, please do not discuss the questionnaire with fellow chief officers. It is vital that I receive information from you that has not been influenced by anyone else.

After the study has been completed, the results will be available from me upon request.

Thanks in advance for your time and participation in this study.

Sincerely,

Don Adams, Deputy Chief
Kings Point Volunteer Fire Department

Appendix C
Survey Cover Letter for Orlando

Chief Officers
Field Operations Bureau
Orlando Fire Department

Dear Fellow Chief Officers:

Presently I am in the National Fire Academy's Executive Fire Officer Program, and as a part of my studies I am required to do a research paper. I have, with the approval of the Fire Chief, chosen to research computer-based assessment that could be used for selecting, designing or purchasing protective clothing ensembles. Once completed, the Fire Chief and training personnel will review the results of this study.

Your full participation in this research will involve: (1) your completion and return of the enclosed two part questionnaire, and (2) your completion of the demographic background sheet.

For confidential reasons, names will not be needed or required. I will be the only person who will be able to link your name with the information you provide. After all my statistics have been compiled and analyzed, the demographic sheets will be separated from the questionnaire.

In order to insure that the results are valid, please do not discuss the questionnaire with fellow firefighters. It is vital that I receive information from you that has not been influenced by anyone else.

After the study has been completed, the results will be available from me upon request.

Thanks in advance for your time and participation in this study.

Sincerely,

Don Adams, District Chief
Orlando Fire Department

Appendix D
Demographic Sheet

Please check the appropriate category for each section below.

1. YEARS IN THE FIRE SERVICE:

- ❑ 1 to 5 years
- ❑ 6 to 10 years
- ❑ 11 to 15 years
- ❑ 16 to 20 years
- ❑ 21 to 25 years
- ❑ 26 years

2. RANK

- ❑ District Chief
- ❑ Assistant Chief
- ❑ Deputy Chief
- ❑ Fire Chief

3. SEX

- ❑ Male
- ❑ Female

4. RACE

- ❑ Caucasian
- ❑ African-American
- ❑ Asian
- ❑ Other

HERITAGE

- ❑ Hispanic

Appendix D (cont'd)

5. AGE

- ❑ 18-25
- ❑ 26-30
- ❑ 31-35
- ❑ 36-40
- ❑ 41-45
- ❑ 46-50
- ❑ 51-55
- ❑ 56-60
- ❑ 60+

6. EDUCATION

- ❑ High School
- ❑ Some College
- ❑ College--Associate of Arts/Associate of Science
- ❑ College--Bachelor of Arts/Bachelor of Science
- ❑ College--Graduate Degree or Graduate Classes

Appendix E
Questionnaire

Several studies have indicated that the greatest number of injuries to firefighters are due to slips and falls. The assumption is that the slips and falls are a result of impaired balance. As chief officers on emergent and non-emergent incidents, have you seen change-in-support strategies of firefighters such as the ones listed below? Please check all of the following that apply:

- ❑ Compensatory stepping movements
- ❑ Rapid stepping to recover balance
- ❑ Grasping movements of the limbs
- ❑ Rapid volitional arm movements
- ❑ Slips
- ❑ Falls
- ❑ Missed Jumps
- ❑ Other (please describe):

____
____
____
____
____
____
____

Purchasing Protective Ensembles

Comprehensive standards based on qualified test methodologies have eased the difficulty in the selection of protective clothing ensembles. Additionally, the best available testing technology is used to meet the performance criteria set by these standards. Nonetheless, consider your department's past method of selecting and purchasing protective clothing ensembles, as well as if your department performs any further testing of ensembles before procurement of the ensembles. Think of the entire fire service as you answer the following questions.

What is your methodology for purchasing protective clothing ensembles?

____
____
____
____

Appendix E (cont'd)

As a visionary, what are some innovative methodologies for the selection or purchase of protective clothing ensembles that could be implemented now to provide the best data on the effect of new equipment and protective clothing ensembles on balance and safety?

Consider the vast changes that have occurred over the past several years regarding the improvement of protective clothing ensembles as you answer the next question. Also, envision those changes which you think may occur in the next few years.

If you had total utopian, what are several things that the fire service could do to provide the best protective clothing ensembles for safety and balance?

If computer-based assessment was used to provide beneficial data on the effect of new equipment and protective clothing ensembles on balance and safety, what are some of your perceived barriers?

Appendix F
Demographic Characteristics For Osceola County Fire Department

Years in the Department

Number of years	Number of Personnel	Percentage
1 - 5	8	38%
6 - 10	1	4.5%
11 - 15	1	4.5%
16 - 20	7	33%
21 - 25+	3	14%

Rank

District Chief	Assistant Chief	Deputy Chief	Fire Chief
0	11	1	9
0%	52%	5%	43%

Sex

Male	Female
16	5
76%	24%

Race / **Heritage**

Caucasian	African-American	Asian	Other	Hispanic
20	0	0	0	1
100%	0.0%	0%	0%	5%

Age

Range	Number of Personnel	Percentage
19-25	5	25%
26-30	2	10%
31-35	5	25%
36-40	3	15%
41-45	2	10%
46-50	3	20%

Appendix F (cont'd)

Education **Educational Level:**	**Number of personnel**	**Percentage**
High School	12	60%
Some College	4	20%
A.A./A.S.	2	10%
B.A./B.S.	1	5%
Graduate Degree or Graduate Classes	1	5%

Appendix G
Demographic Characteristics for Orlando Fire Department

Years in the Department

Number of years	Number of Personnel	Percentage
1 - 5	0	0%
6 - 10	0	0%
11 - 15	1	10%
16 - 20	3	30%
21 - 25+	6	60%

Rank

District Chief	Assistant Chief	Deputy Chief	Fire Chief
7	3	0	0
70%	30%	0%	0%

Sex

Male	Female
8	1
80%	10%

Race / **Heritage**

Caucasian	African-American	Asian	Other	Hispanic
8	1	0	0	1
80%	10%	0%	0%	10%

Age

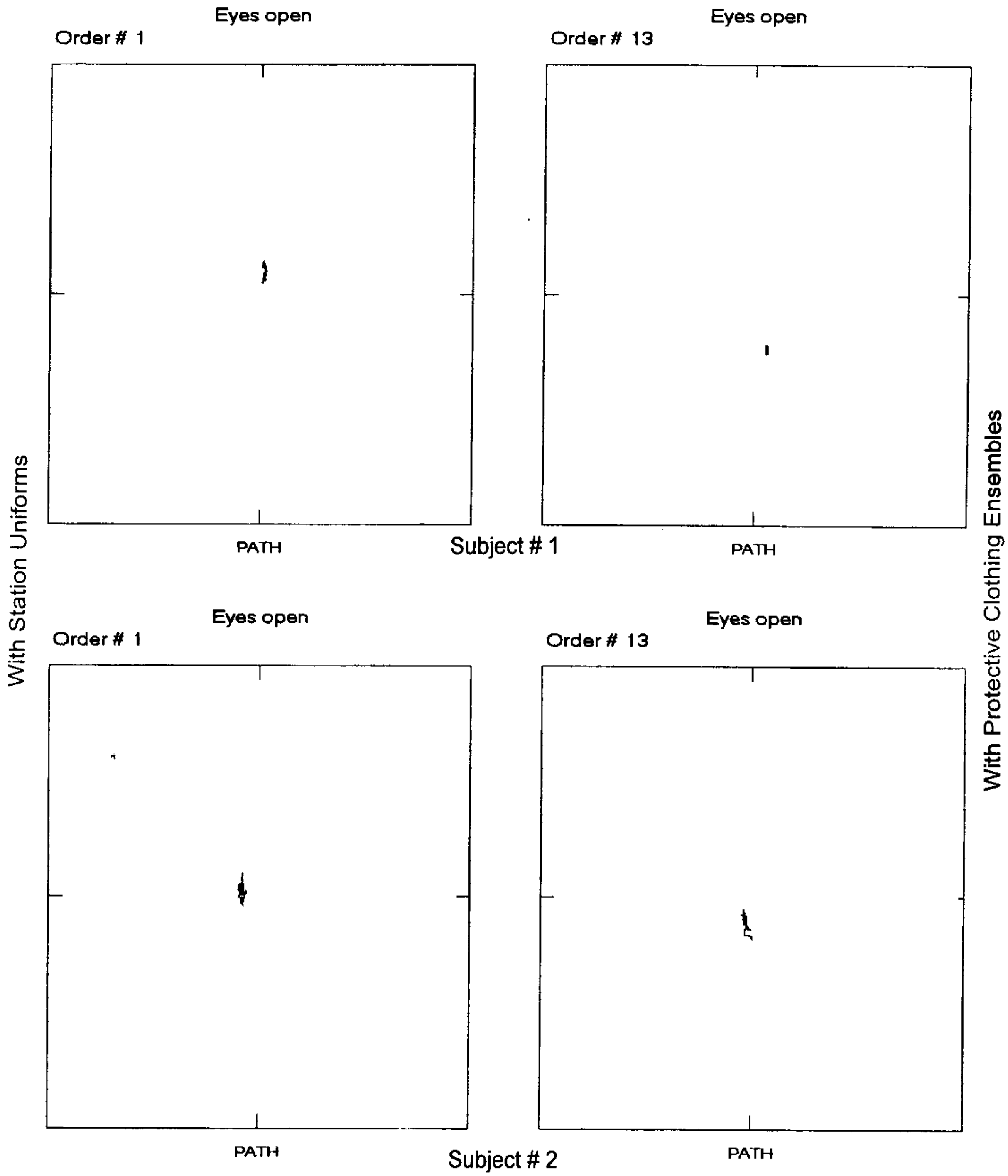
Range	Number of Personnel	Percentage
19-25	0	0%
26-30	0	0%
31-35	1	10%
36-40	4	40%
41-45	4	40%
46-50	1	10%

Appendix G (cont'd)

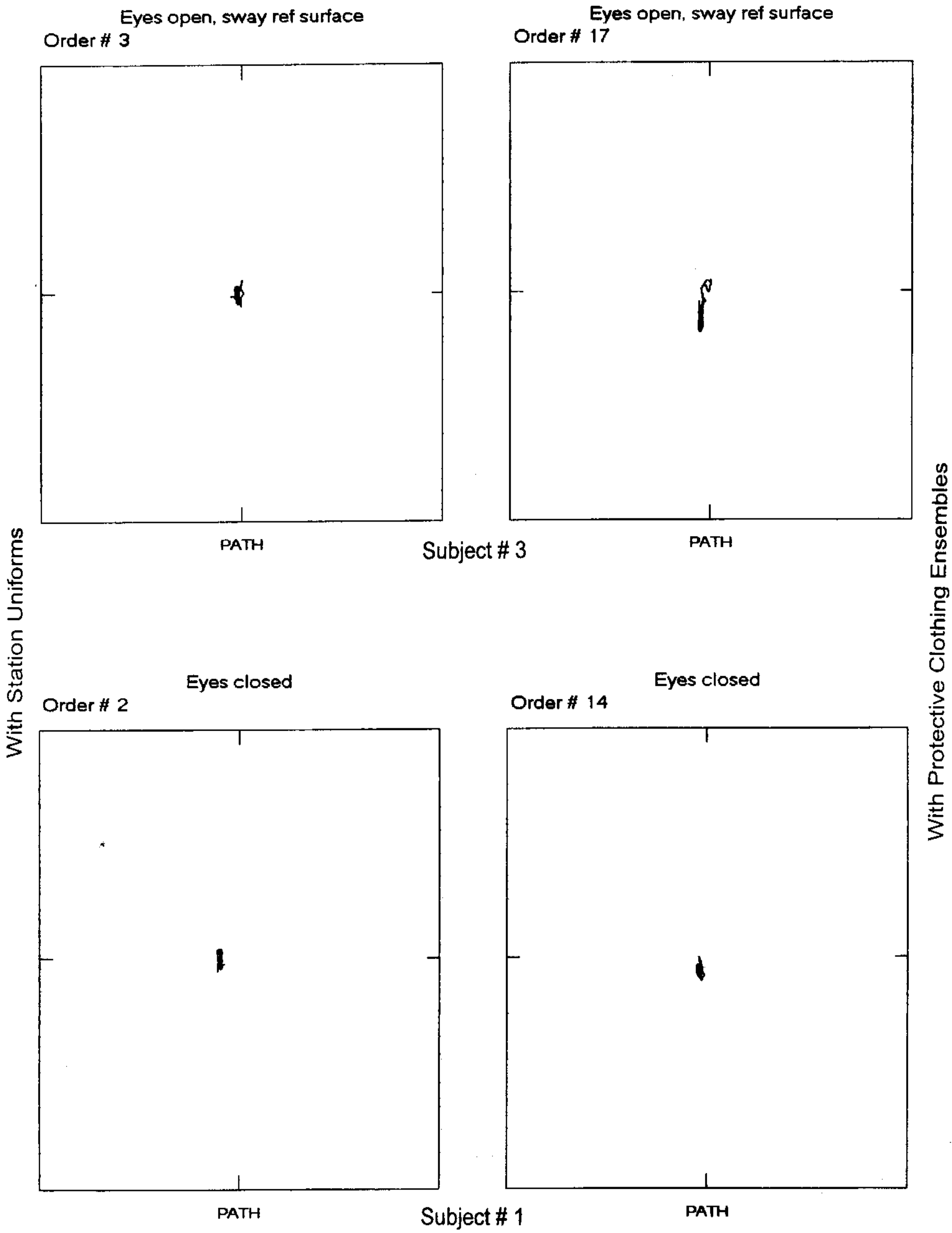
Education **Educational Level:**	**Number of personnel**	**Percentage**
High School	0	0%
Some College	7	70%
A.A./A.S.	1	10%
B.A./B.S.	1	10%
Graduate Degree or Graduate Classes	1	10%

Appendix H

Actual Sway and Position of COG in Three Sensory Tests 1-3 Under Conditions #1 (Station Uniform) and Condition #2 (Protective Clothing Ensembles)



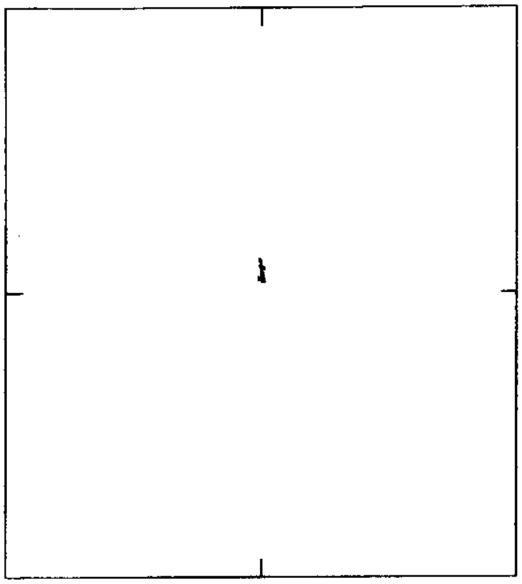
Appendix H (cont'd)



Appendix H (cont'd)

With Station Uniforms

Eyes closed
Order # 2



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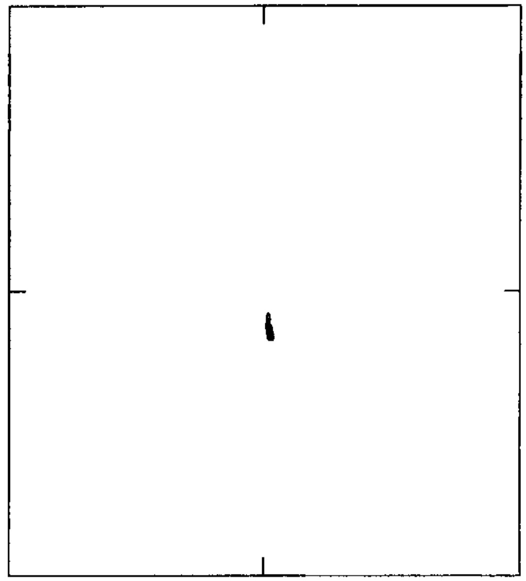
Eyes closed
Order # 14



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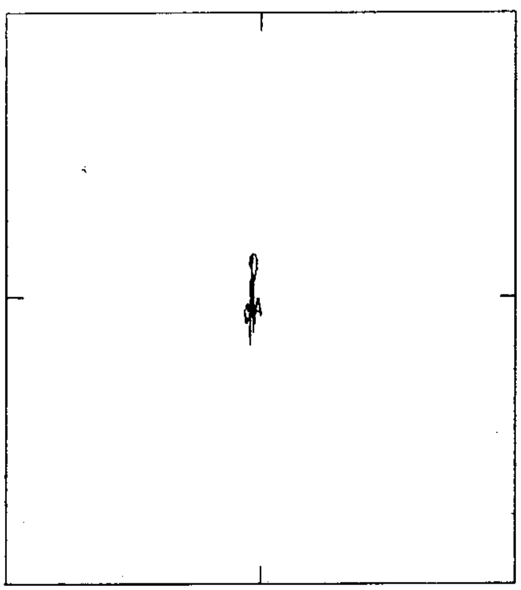
Subject # 2

Eyes closed, sway ref surface
Order # 4



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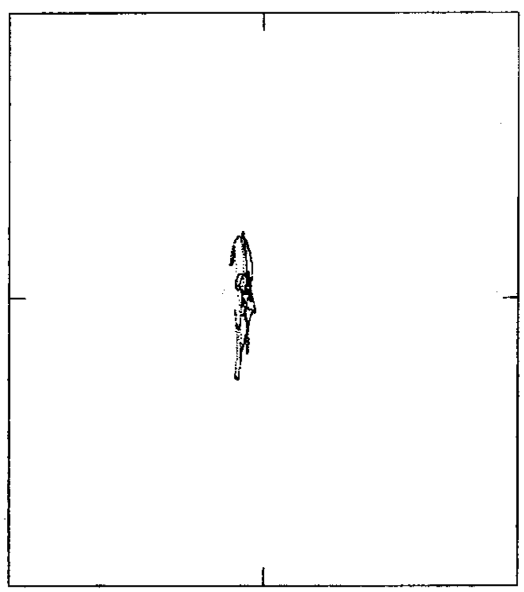
Eyes closed, sway ref surface
Order # 20



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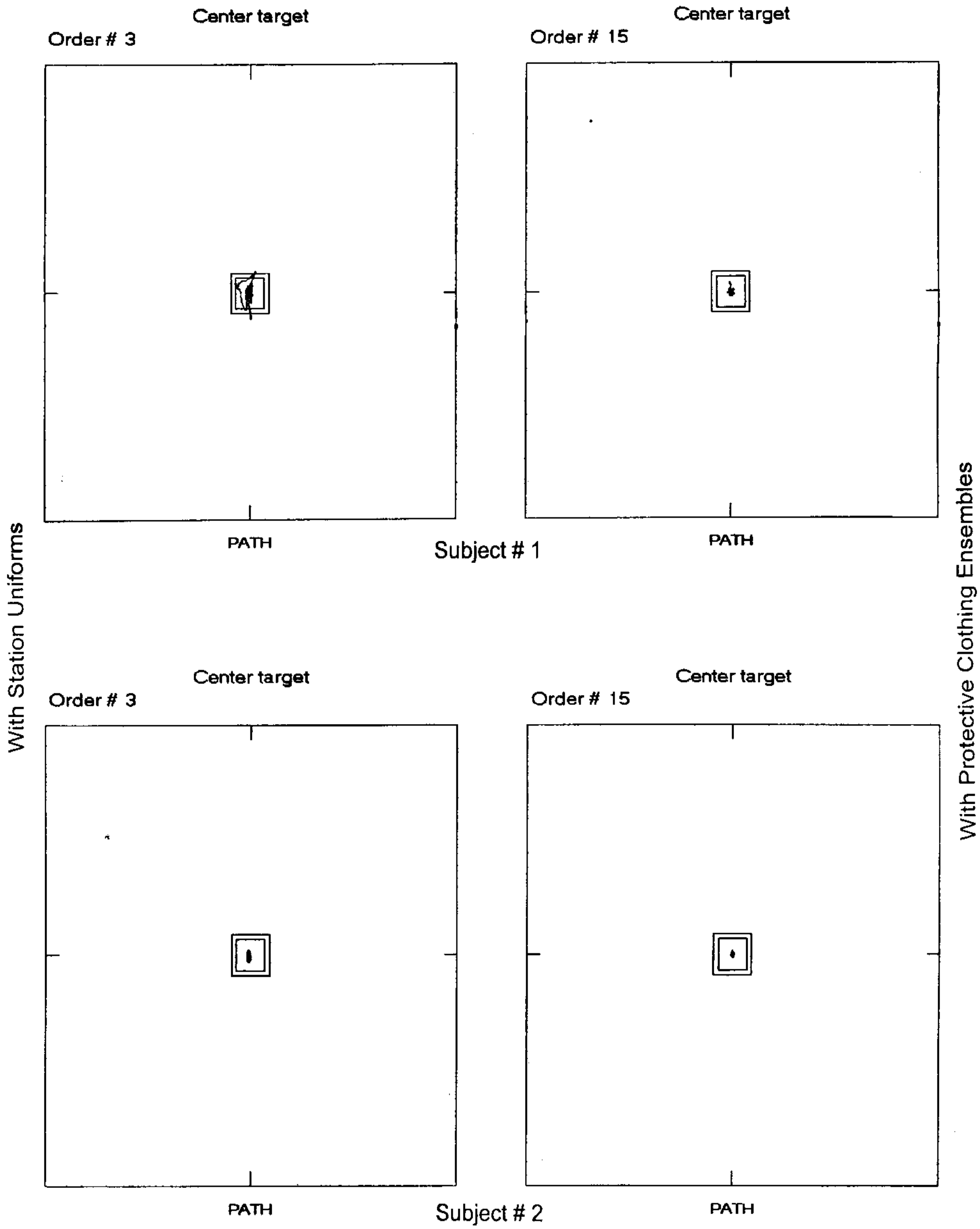
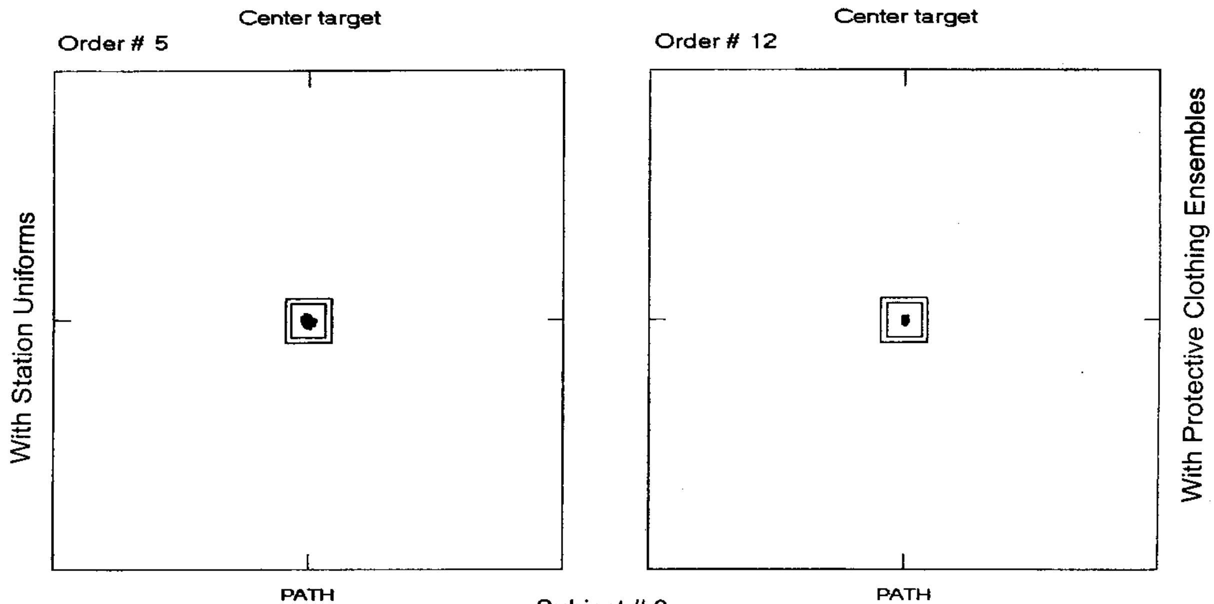
Subject # 3

With Protective Clothing Ensembles

Appendix H (cont'd)



Appendix H (cont'd)



Subject # 3

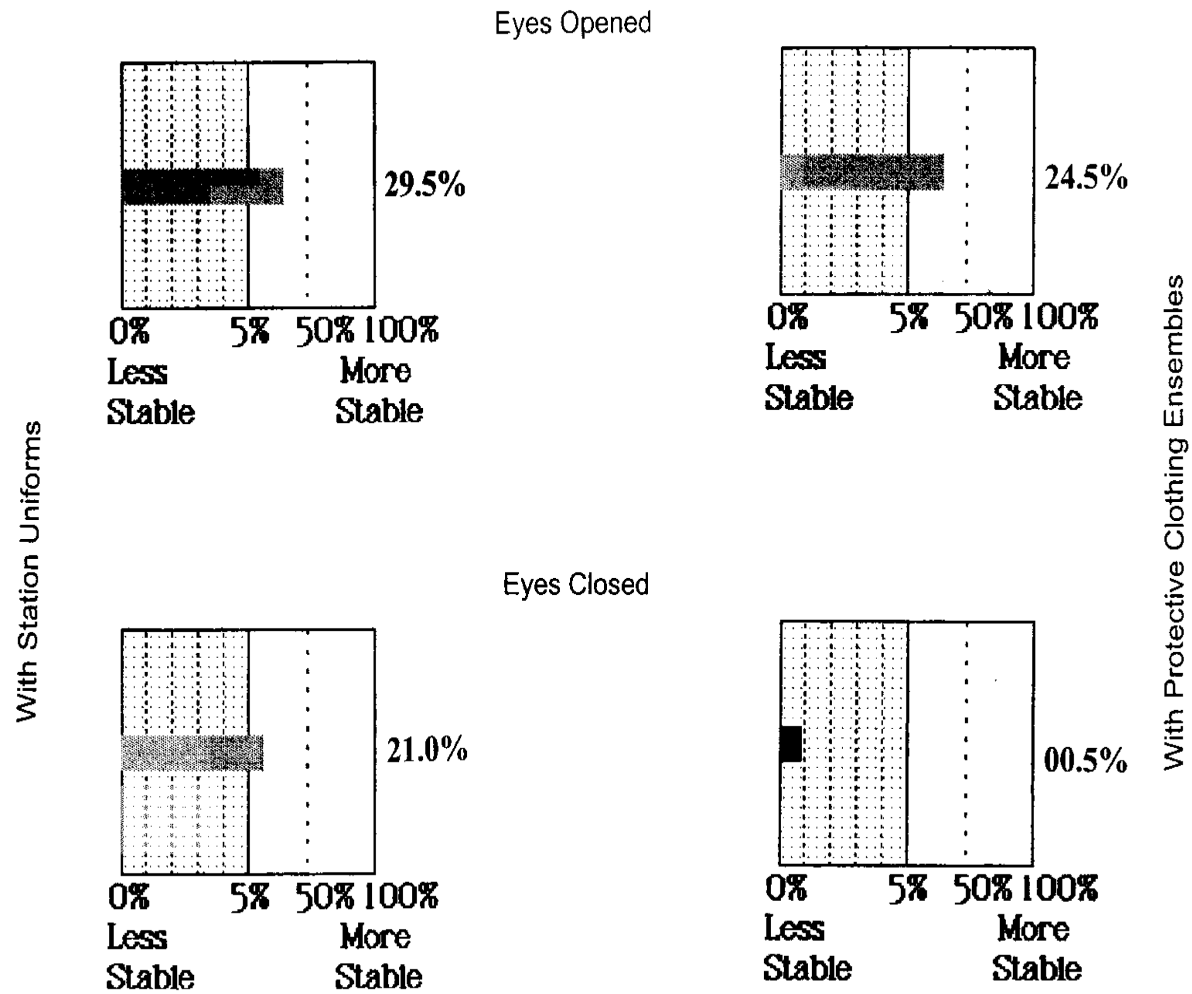
DATA ANALYSIS

	On axix velocity (deg/sec)	Directional Control %
SLOW	**1.8**	**61**
MOD	**2.4**	**71**
FAST	**5.3**	**91**
COMP	**3.2**	**74**

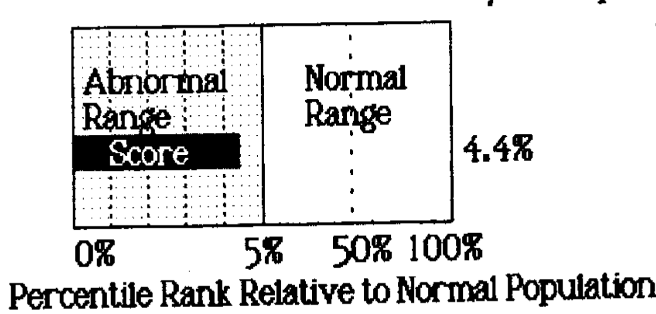
DATA ANALYSIS

	On axix velocity (deg/sec)	Directional Control %
SLOW	**1.6**	**82**
MOD	**2.6**	**87**
FAST	**5.6**	**91**
COMP	**3.3**	**87**

Appendix I
Sway and Position of COG Compared to Normative Data in Three Sensory Tests 1-3 (EO, EC, CT)

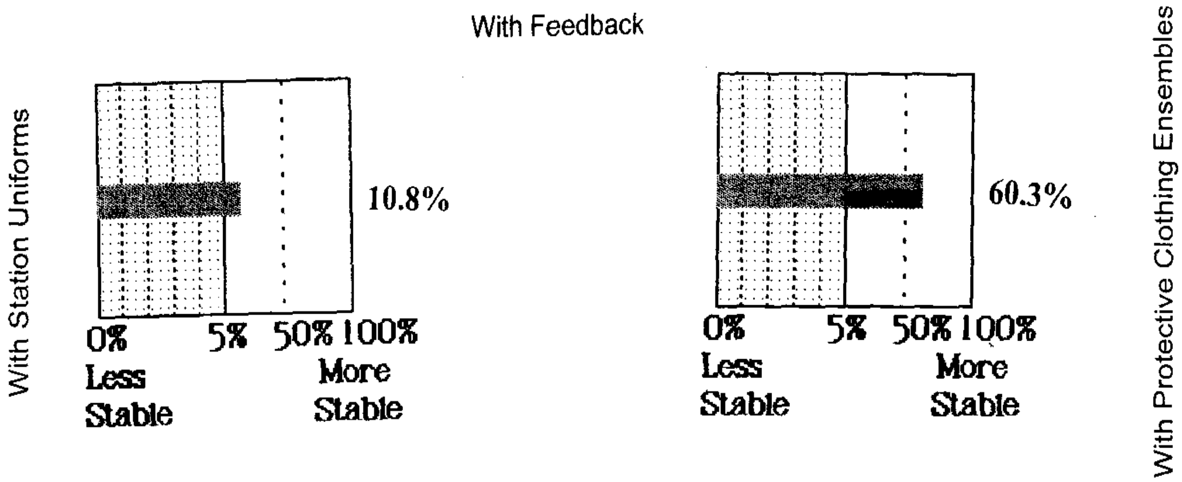


Key to Graphs

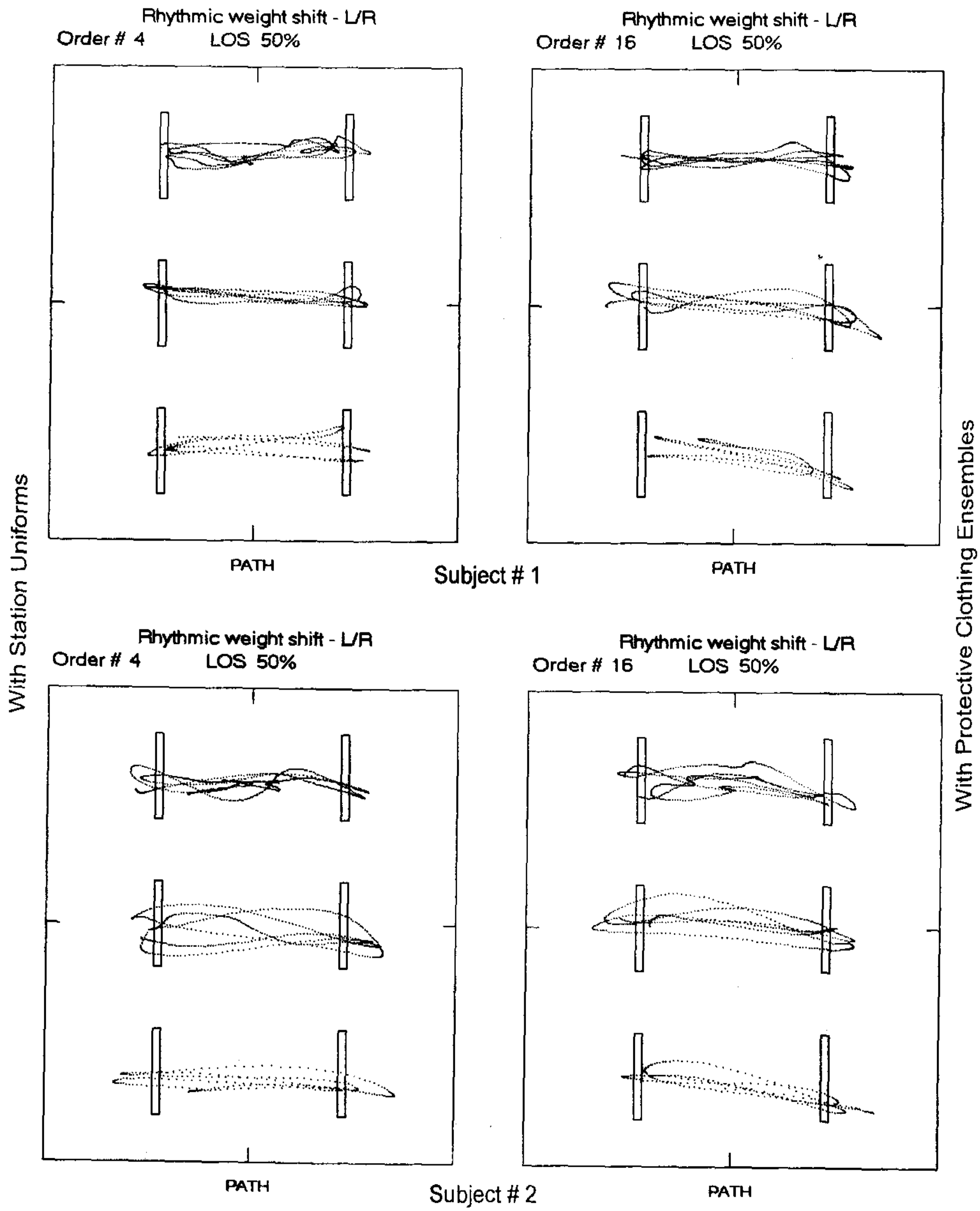


Note: Scores are percentiles relative to a clinically normal (asymptomatic) population.
50% represents an average score.
5% or less (shaded area) represents a clinically abnormal score.

Appendix I (cont'd)



Appendix J
Demonstrates the Ability to Keep Up with a Set Pace and Change Directions Quickly Under Condition #1 Compared to Condition #2 at Three Speeds

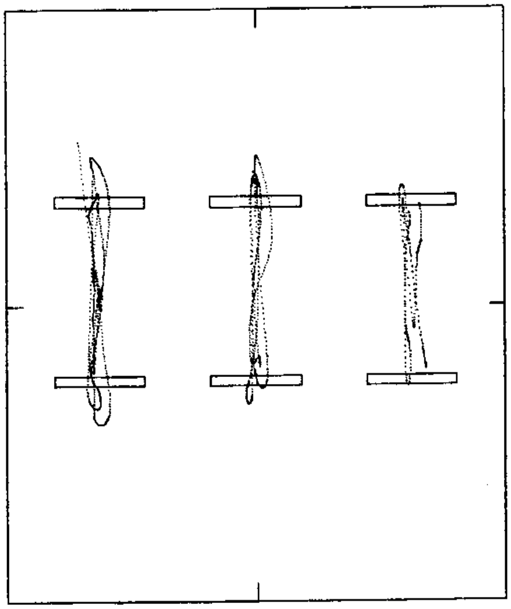


Appendix J (cont'd)

With Station Uniforms

With Protective Clothing Ensembles

Rhythmic weight shift - F/B
Order # 5 LOS 50%



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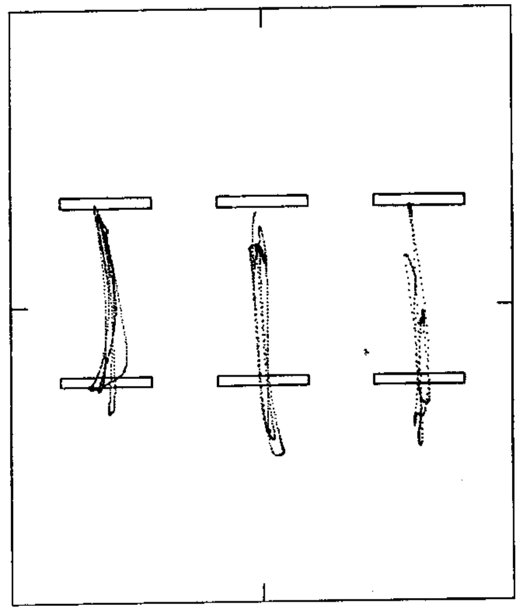
Rhythmic weight shift - F/B
Order # 17 LOS 50%



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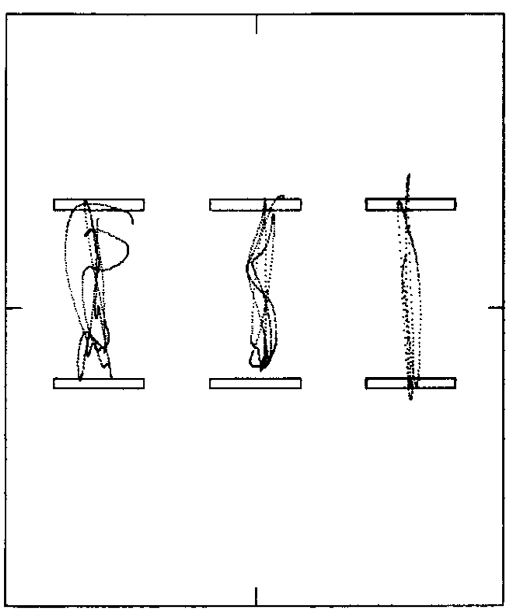
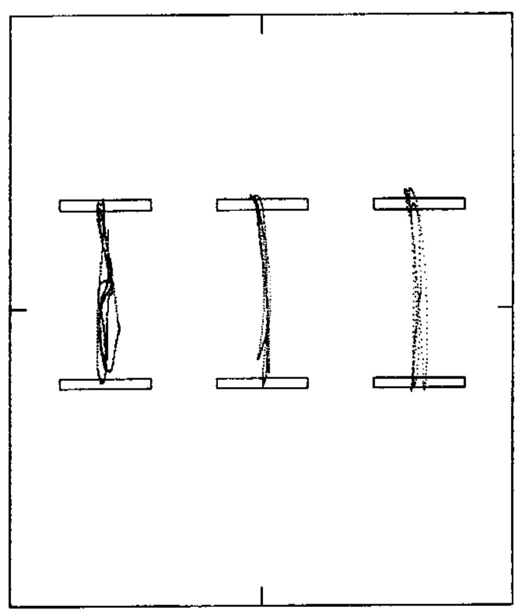
Subject # 2

Rhythmic weight shift - F/B
Order # 7 LOS 50%



PATH

Rhythmic weight shift - F/B
Order # 14 LOS 50%

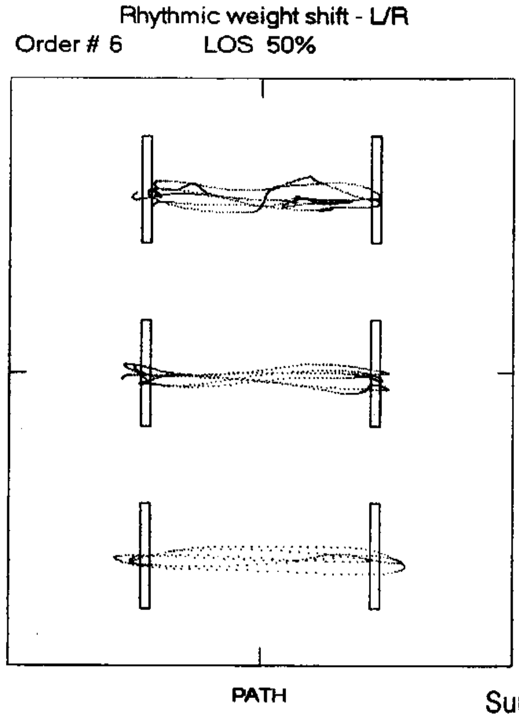


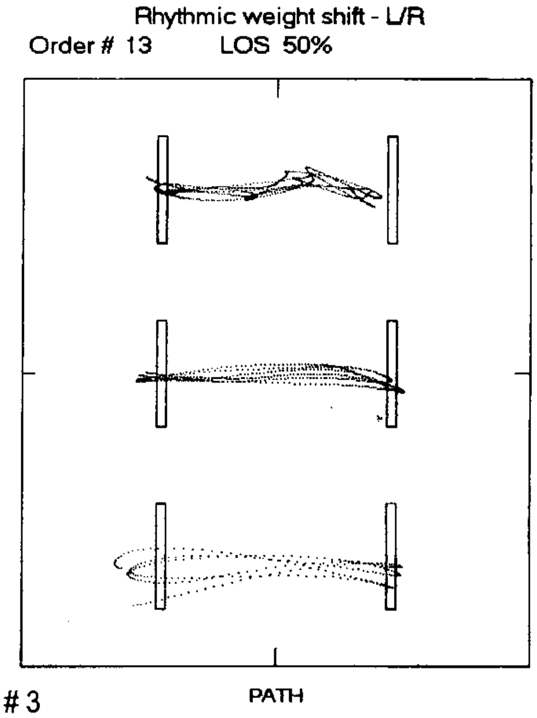
PATH

Subject # 3

Appendix J (cont'd)

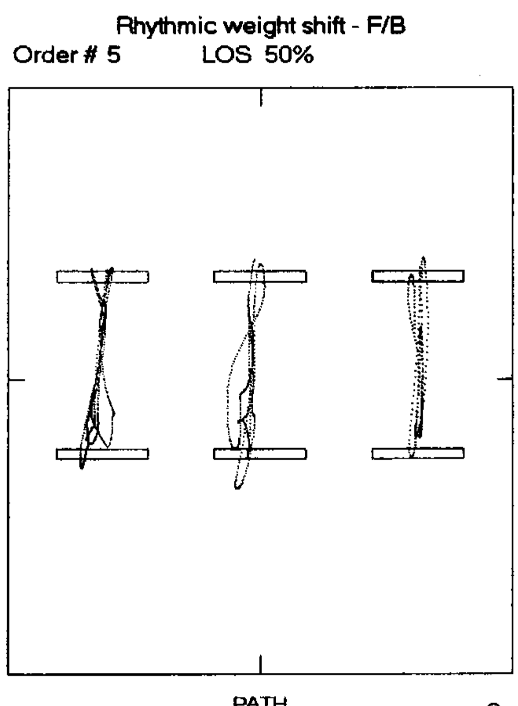
With Station Uniforms

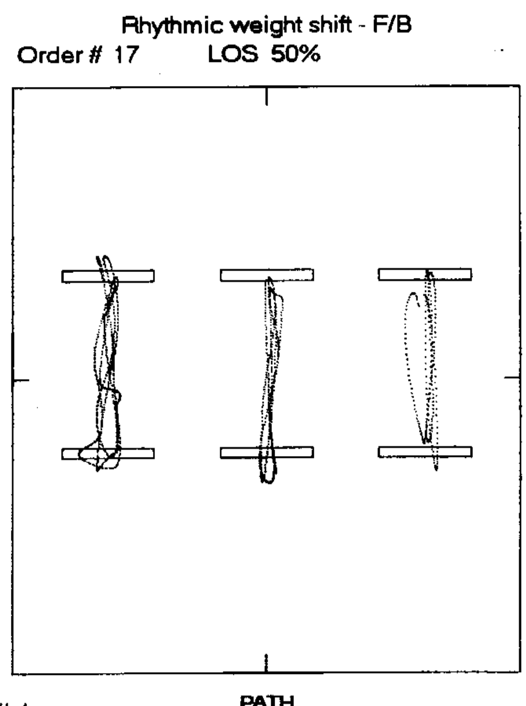




Subject # 3

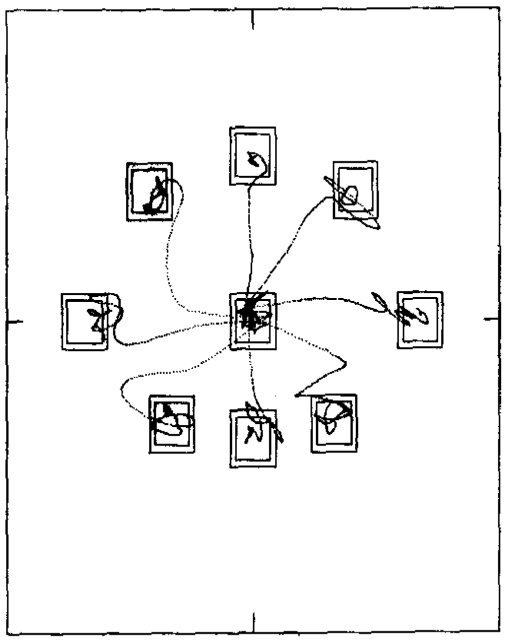
With Protective Clothing Ensembles

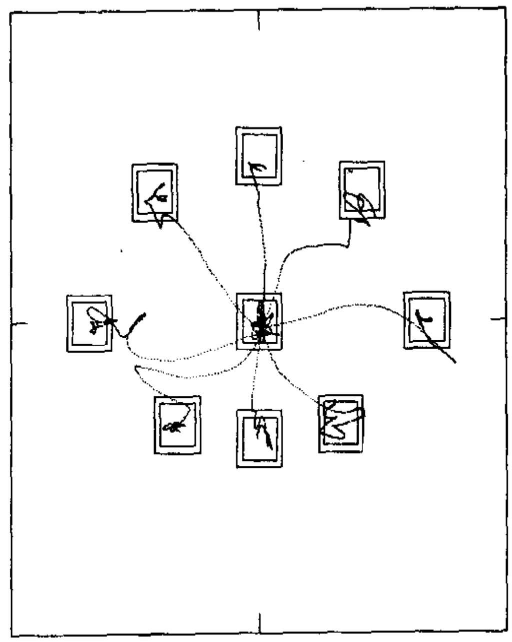




Subject # 1

Appendix K
Demonstrates the Standard Limits of Stability Tests at 75 Percent in Condition #1 Compared to Condition #2





DATA ANALYSIS

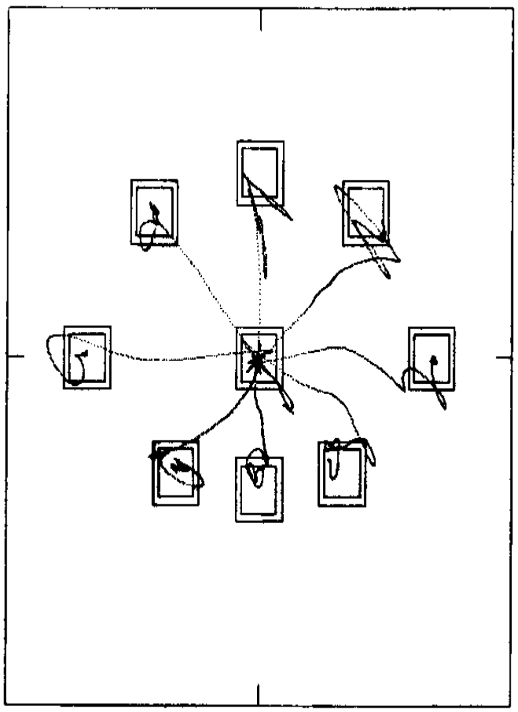
Transition		RT (sec)	MVL (deg/sec)	EPE %	MXE %	DCL %
1	(F)	0.58	1.6	76	76	93
2	(RF)	1.00	2.3	73	76	81
3	(R)	0.44	3.7	60	78	91
4	(RB)	0.44	5.3	59	80	74
5	(B)	0.44	2.8	77	78	75
6	(LB)	0.40	5.0	87	87	65
7	(L)	1.00	3.7	62	74	89
8	(LF)	0.54	4.4	74	76	83

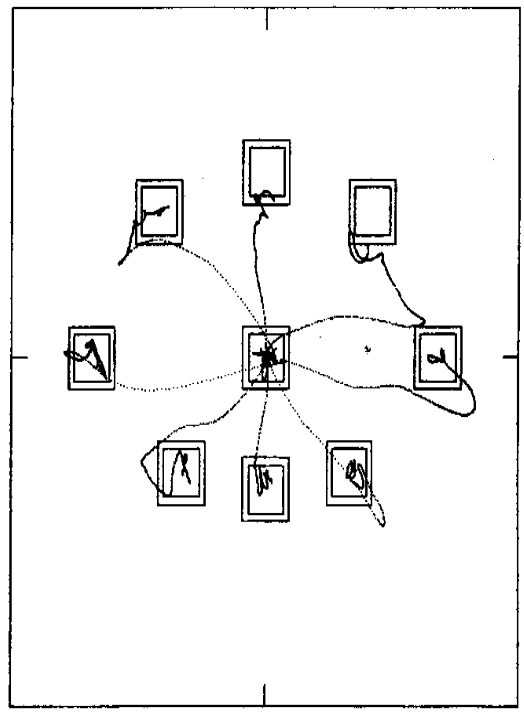
DATA ANALYSIS

Transition		RT (sec)	MVL (deg/sec)	EPE %	MXE %	DCL %
1	(F)	1.12	1.8	72	72	93
2	(RF)	0.52	2.3	67	74	85
3	(R)	1.02	4.0	87	87	85
4	(RB)	0.42	3.1	83	83	84
5	(B)	0.44	3.5	57	81	91
6	(LB)	0.58	4.0	74	83	64
7	(L)	0.60	5.0	59	76	88
8	(LF)	1.14	3.6	65	76	92

Subject # 1

Appendix K (cont'd)





DATA ANALYSIS

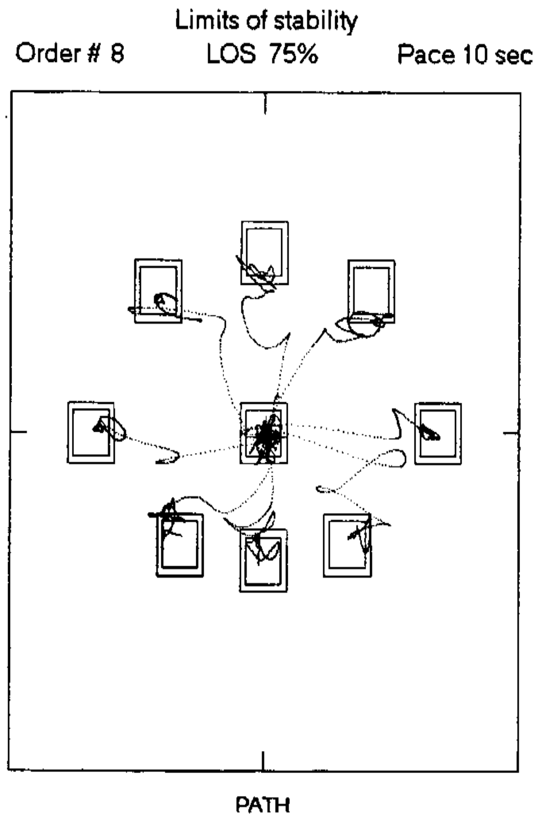
Transition		RT (sec)	MVL (deg/sec)	EPE %	MXE %	DCL %
1	(F)	0.68	4.9	58	75	80
2	(RF)	0.78	2.5	75	79	71
3	(R)	1.32	3.4	64	81	84
4	(RB)	0.16	3.7	86	86	67
5	(B)	0.56	1.5	60	73	89
6	(LB)	0.12	2.5	82	82	55
7	(L)	0.58	4.2	92	92	93
8	(LF)	0.62	4.0	76	79	87

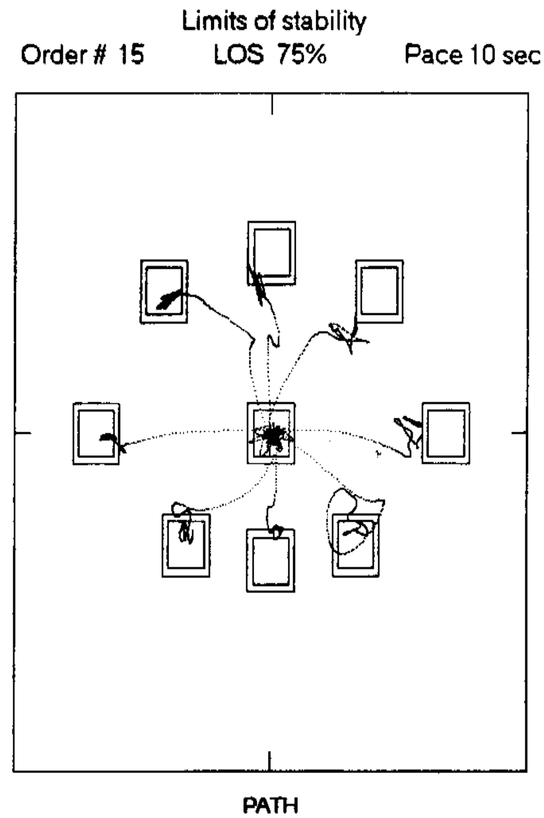
DATA ANALYSIS

Transition		RT (sec)	MVL (deg/sec)	EPE %	MXE %	DCL %
1	(F)	1.36	1.1	58	67	89
2	(RF)	1.22	3.1	66	68	44
3	(R)	0.66	2.8	91	91	80
4	(RB)	N/S	N/S	N/S	N/S	N/S
5	(B)	0.40	2.3	78	78	88
6	(LB)	0.50	3.0	90	90	78
7	(L)	0.58	5.6	87	87	92
8	(LF)	0.80	4.9	76	81	76

Subject # 2

Appendix K (cont'd)





DATA ANALYSIS

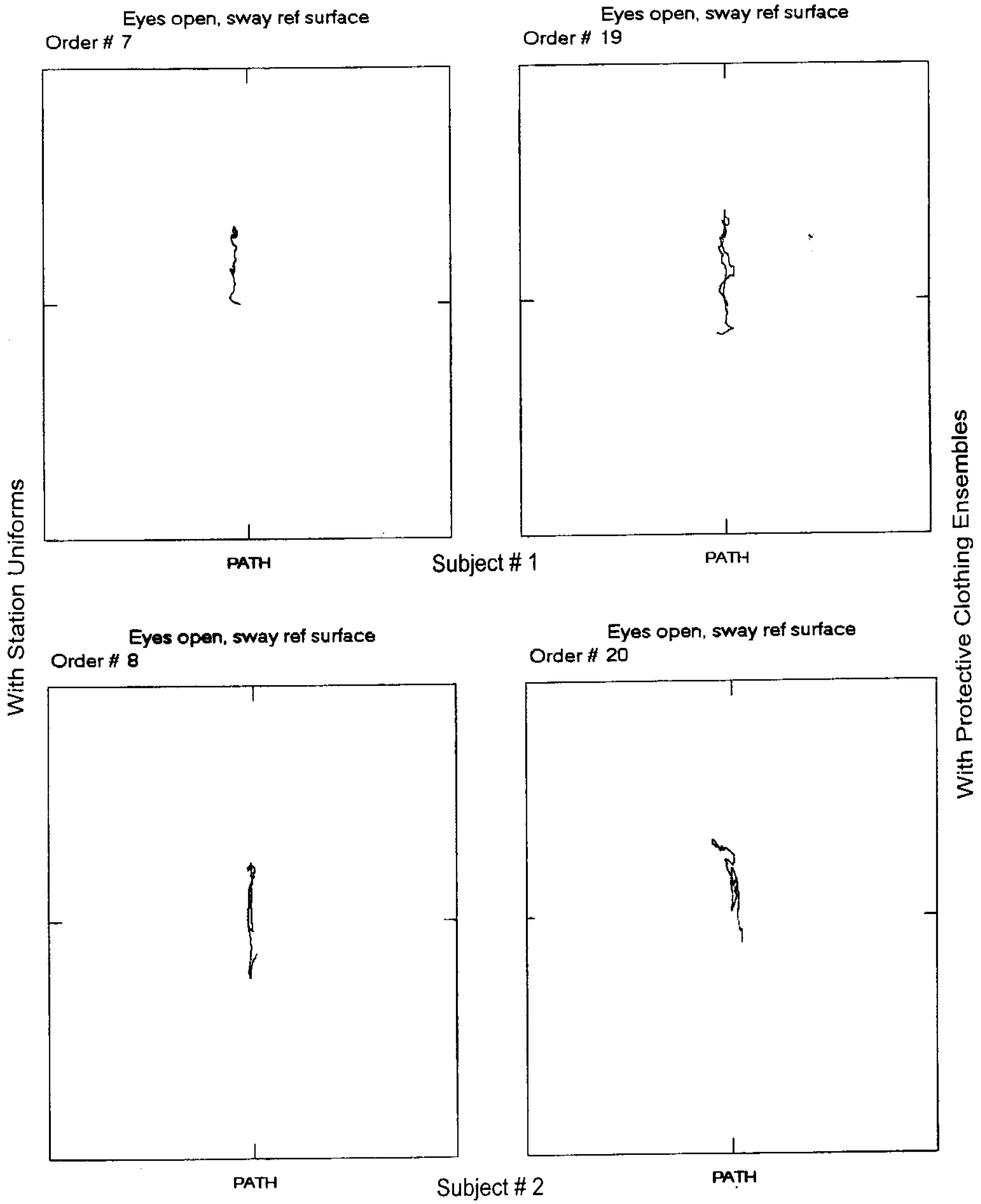
Transition		RT (sec)	MVL (deg/sec)	EPE %	MXE %	DCL %
1	(F)	0.42	5.5	42	73	80
2	(RF)	0.46	5.1	49	76	80
3	(R)	0.50	7.9	59	76	93
4	(RB)	0.38	7.7	73	87	45
5	(B)	0.40	3.5	55	77	68
6	(LB)	0.46	3.6	79	80	75
7	(L)	0.56	6.6	47	74	90
8	(LF)	0.48	4.2	81	81	83

DATA ANALYSIS

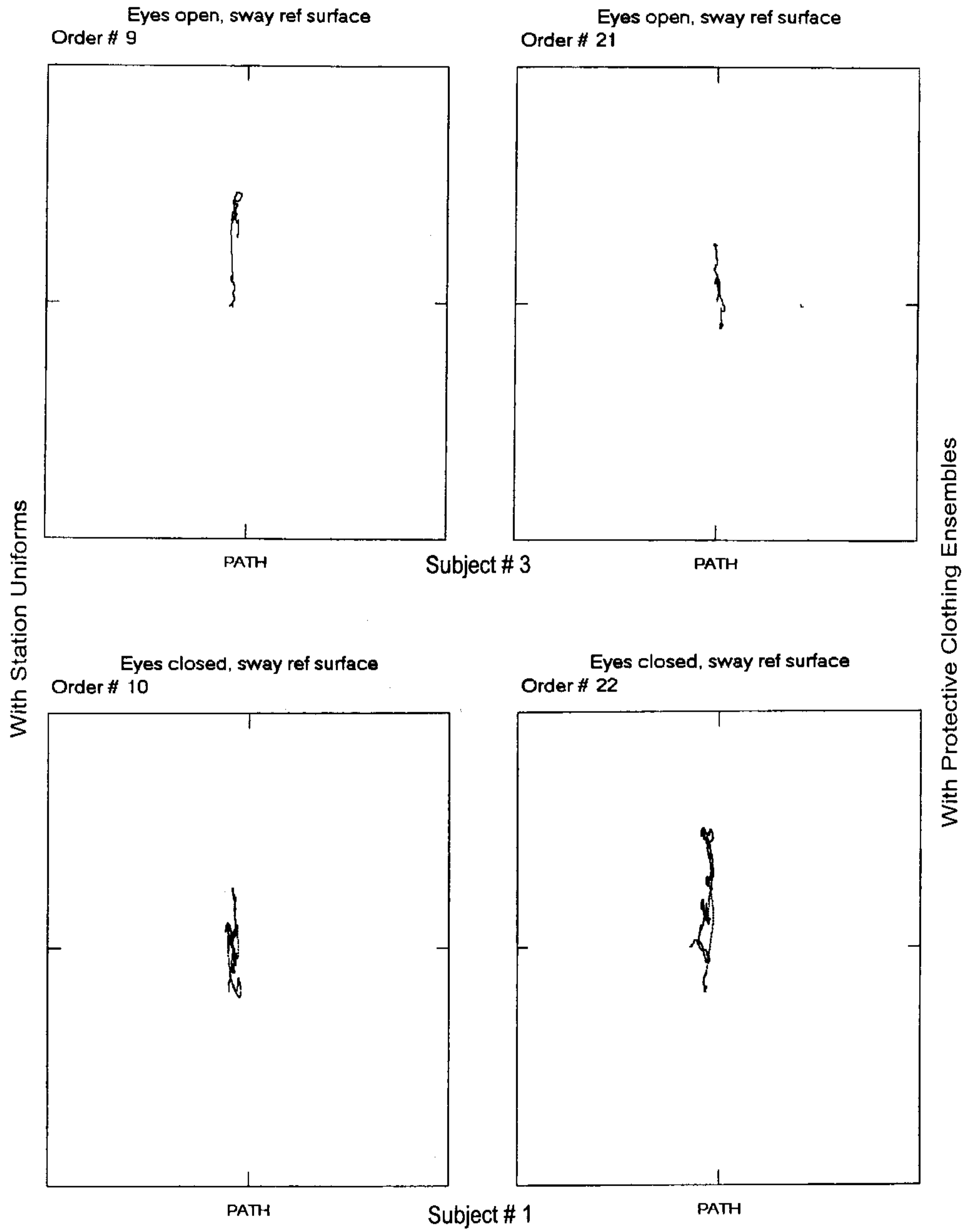
Transition		RT (sec)	MVL (deg/sec)	EPE %	MXE %	DCL %
1	(F)	0.52	5.1	41	70	81
2	(RF)	0.50	3.1	58	59	82
3	(R)	0.50	5.0	60	65	91
4	(RB)	0.48	3.9	77	77	71
5	(B)	0.84	3.6	44	63	87
6	(LB)	0.62	3.9	70	76	82
7	(L)	0.62	5.8	65	73	94
8	(LF)	1.26	2.7	71	74	81

Subject # 3

Appendix L
Actual Sway/Stability and COG Position Under Two Sensory Tests 8 and 9, Eyes Open Sway Referenced Surface and Eyes Closed Sway Referenced Surface Under Condition #1 and #2



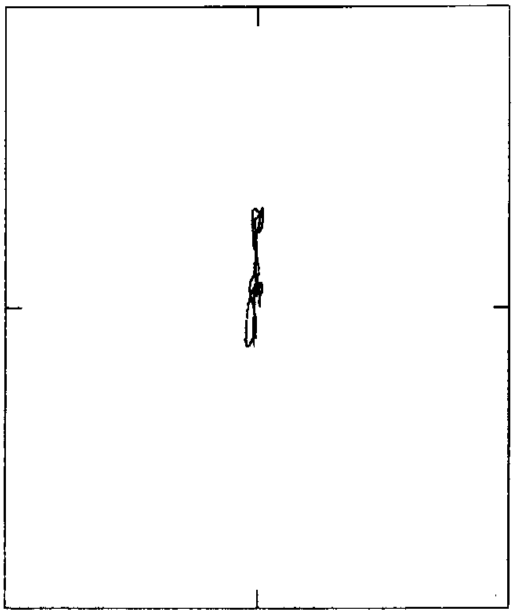
Appendix L (cont'd)



Appendix L (cont'd)

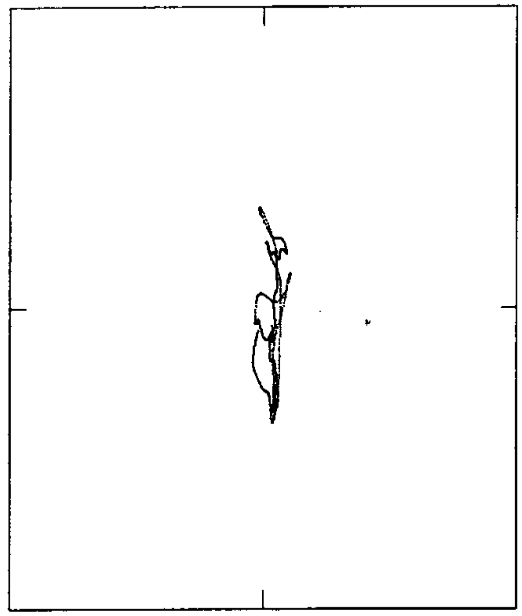
With Station Uniforms

Eyes closed, sway ref surface
Order # 10



PATH

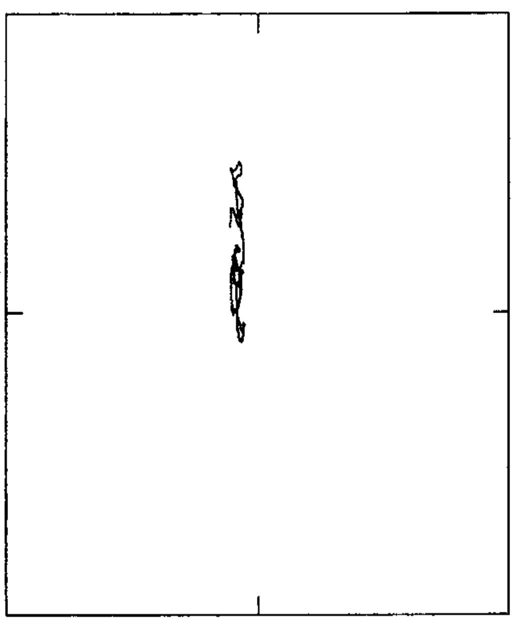
Eyes closed, sway ref surface
Order # 22



PATH

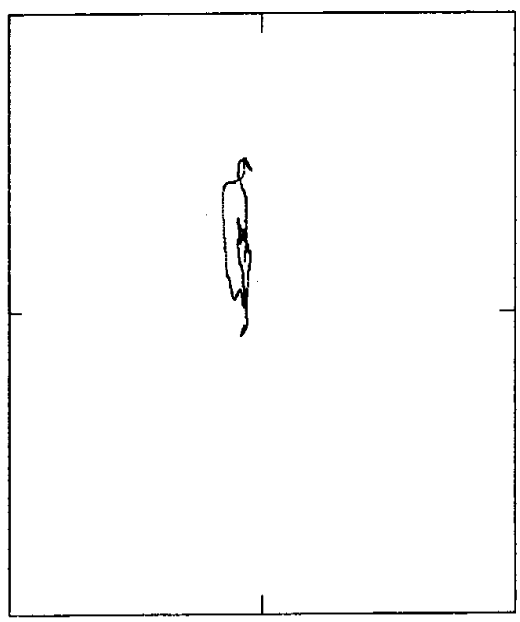
Subject # 2

Eyes closed, sway ref surface
Order # 11



PATH

Eyes closed, sway ref surface
Order # 23



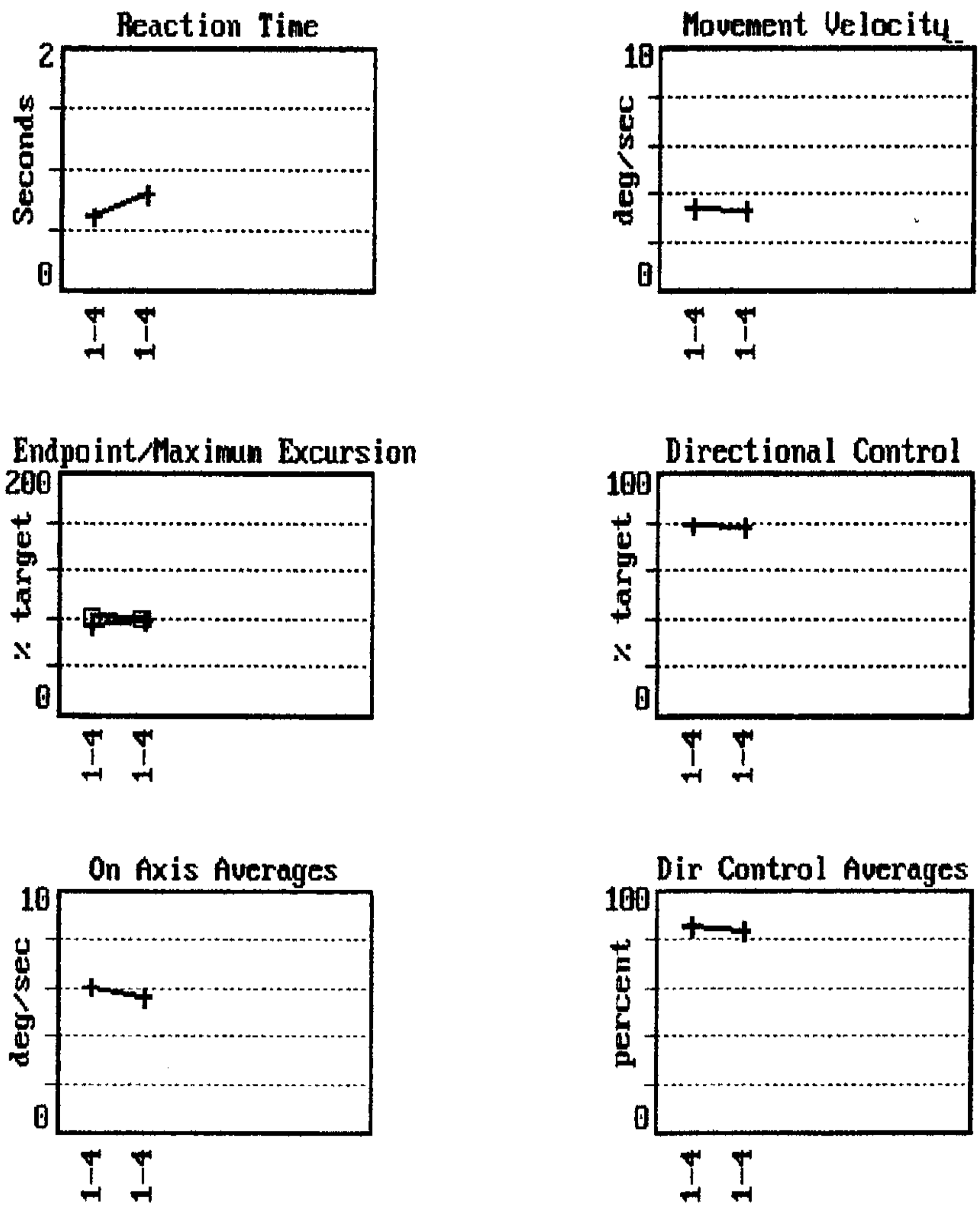
PATH

Subject # 3

With Protective Clothing Ensembles

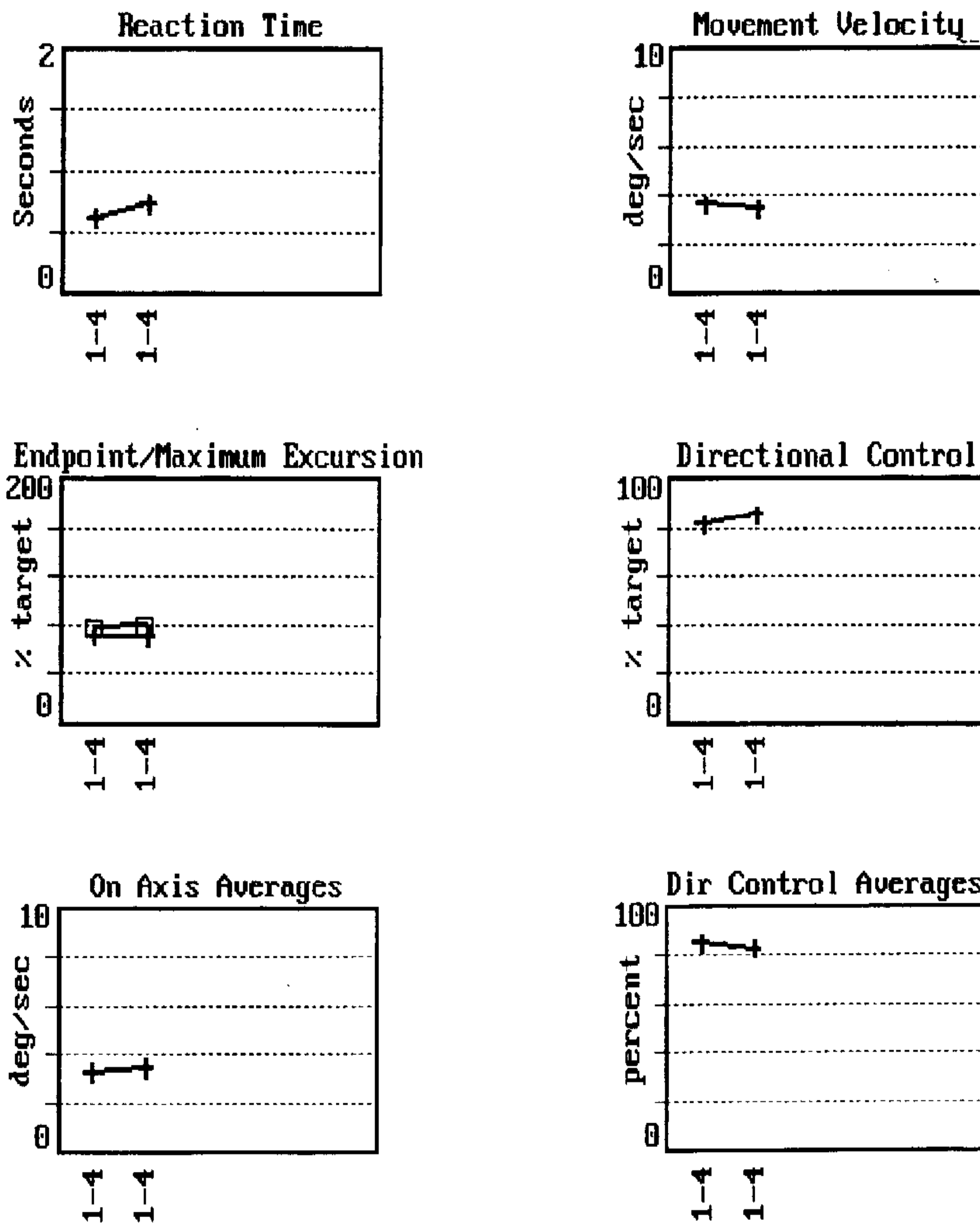
Appendix M
Demonstrates Stability Under Three Sensory Tests #2, #8, and #9 In Condition #1 and Condition #2

With Station Uniforms



Appendix M (cont'd)

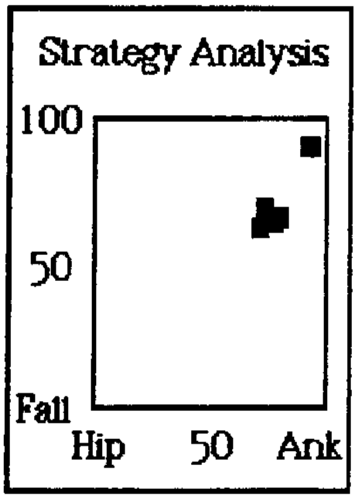
With Protective Clothing Ensembles

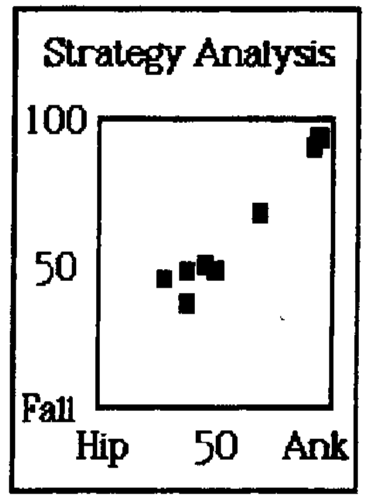


Appendix N
Stability and Type of Strategy Used to Maintain Stability Under Condition #1 and #2

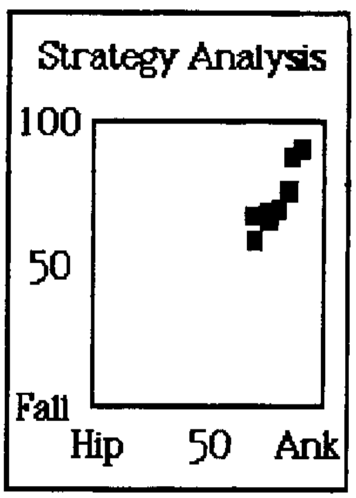
With Station Uniforms

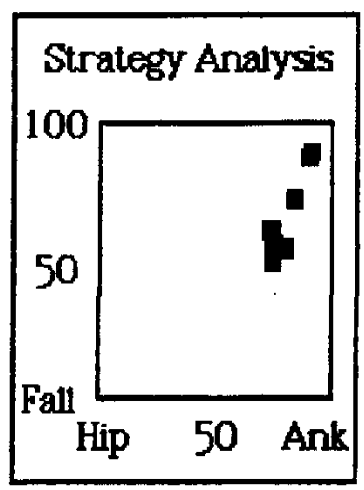
With Protective Clothing Ensembles





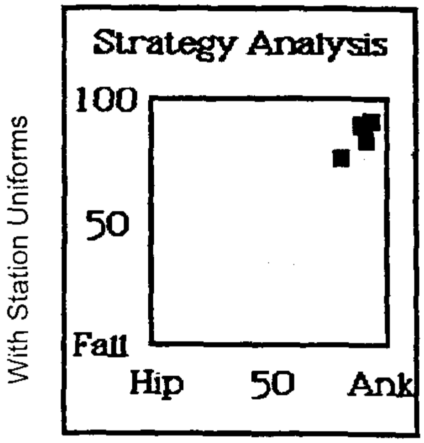
Subject # 1

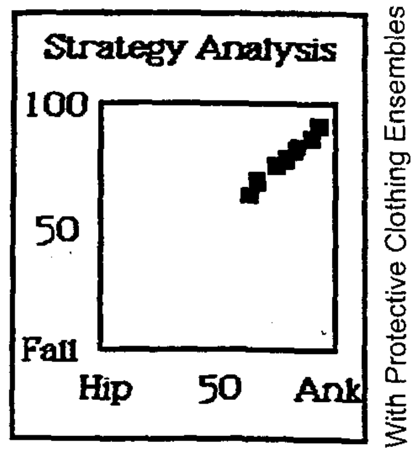




Subject # 2

Appendix N (cont'd)





Subject # 3

Appendix O
Sway Generation Under Condition #1 and #2 in Five Sensory Tests

Sensory Test	Condition #1 Sway (% Max Area)	Condition #2 Sway (% Max Area)
#1 (EO)	0.08	0.08
#2 (EC)	0.16	0.28
#3 (CT)	0.09	0.04
#8 (EO/SS)	0.13	0.30
#9 (EC/SS)	0.37	1.35

Sway Produced Under Five Test